VOLCANIC ROCKS FROM THE CAPE VERDE ISLANDS

GERALD M. PART

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Preface and List of Collections

The British Museum collections contain several sets of rocks from the Cape Verde Islands. The earliest of these is one collected by Major Henry Thomas Colebrooke in 1823; the most recent is the collection made nearly a hundred years later on the *Quest* Expedition in 1922 by Dr. G. Vibert Douglas, now Professor of Geology at Halifax, Nova Scotia. These rocks brought back by the *Quest* Expedition were described by Mr. Gerald M. Part and his account of them was published in the report issued by the Trustees of the Natural History Museum in 1930. Later Mr. Part offered to examine the extensive collection of rocks from the Cape Verde Islands brought back by Mr. Walter Child in 1914. The phonolites proved to be particularly interesting and very varied. Mr. Part has described the more important types, illustrating his descriptions by pen-and-ink drawings which depict clearly the appearance of these rocks as seen under the microscope, and are worthy representatives of a style of illustration adopted by the earlier petrographers and later much used by Alfred Harker and Herbert H. Thomas in Geological Survey Memoirs and in their other published papers and books. Mr. Part's account of the phonolites and related feldspathoidal rocks, and his account of the general geology as it is at present known, will show the richness of the Cape Verde Islands in rare and new varieties of volcanic rocks, and the many problems of their field relations which await investigation on the ground.

I am indebted to Mr. S. E. Ellis of the Department of Mineralogy for the recalculation of many of the norms from the chemical analyses. Our thanks are due to the Editor of the *Geological Magazine* for permission to reproduce Fig. 17.

The following is a complete list of the collections of rocks from the Cape Verde Islands in the Department of Mineralogy, British Museum (Natural History).

1. Specimen 'from an island which rose from the sea near the Cape Verde Is. and sank four hours after'.
   T. Renfree, purchase, 1865. (B.M. 39845)
2. Specimens from S. Tiago and other islands of the Cape Verde Group. Presented to the Geological Society of London by Major Henry Thomas Colebrooke in 1823. 29 specimens.
   The Geological Society of London, presentation, 1911. (B.M. 1911, 1615–16)
3. Specimens collected from S. Tiago by Deputy-Inspector-General (then Surgeon) Robert McCormick during the Antarctic Expedition of 1839–1843 under Sir James Clarke Ross. 6 specimens.
   By bequest, 1890. (B.M. 66387–9)
   The Lords Commissioners of the Admiralty, presentation, about 1847. (B.M. 75365–7)
4. Rock specimens from S. Vicente and S. Tiago collected during the voyage of H.M.S. *Challenger* in 1873 and described by the Abbé A. F. Renard. 29 specimens.
   The Lords Commissioners of the Admiralty, presentation (through Sir John Murray), 1890. (B.M. 64607–32 and B.M. 1920, 668: 17–19)

5. Specimens from S. Vicente. 5 specimens.
   Dr. J. W. Evans, presentation, 1894. (B.M. 74332–36)
6. Specimens collected by the donor from the Cape Verde Is. 857 specimens.
   Walter Child, presentation, 1915. (B.M. 1915, 130)
7. Specimen from M. Verde, S. Vicente.
   Dr. David A. Bannerman, presentation. (B.M. 1919, 161)
8. Specimens from S. Vicente collected on the *Quest* Expedition by Dr. G. Vibert Douglas. 24 specimens.
   The Shackleton–Rowett (*Quest*) Expedition, 1922, presentation, 1927.
   (B.M. 1927, 1245)

W. CAMPBELL SMITH,
Keeper of Minerals.

I. Introduction

The large collection of rocks from the Cape Verde Islands presented to the British Museum (Natural History) in 1915 by Mr Walter Child comprises 857 specimens from the islands of S. Antão, S. Vicente, S. Tiago, Fogo, and Brava. I have been able to examine this collection, and, by the courtesy of Professor C. E. Tilley, F.R.S., I have also been allowed to re-examine in the Department of Mineralogy and Petrology at Cambridge the collection made by Charles Darwin during the voyage of H.M.S. *Beagle* (1831–1836).

I take this opportunity to express my thanks to Professor Tilley, to the staff of his Department, and to Dr. S. R. Nockolds in particular for kindly help and criticism throughout my work at Cambridge. A grant from the Government Grants Committee of the Royal Society enabled me to have several new chemical analyses made. This grant is gratefully acknowledged and I am obliged to Mr. H. B. Milner (Geochemical Laboratories) and to Mr. W. H. Herdsman for having carried out the work.

Mr. Walter Child made his collection during a stay in the islands in 1914. He deserves to have it put on record that he succeeded in bringing home—in war-time—the most important collection of rocks from the Cape Verde Islands at present in this country.

From the manuscript catalogue which accompanies his collection it is clear that Mr. Child had access to the work of Friedlaender (1913) and based his localities upon the maps published by that author. Unfortunately some of his place-names do not correspond with those on the official Portuguese maps. So far as I have been able to identify them the chief discrepancies are as follows:

Brava. 'Minhoto' = Covoada, 2½ km. west of Furna.

'Povoação'. This word is Portuguese for 'village'. The village referred to is situated about 5 km. south-west of Furna on the Porto dos Ferreiros road.

R. 'Lacacan', probably R. Sta. Barbara, south of Furna.

Future workers should have no difficulty in identifying Child's locality, which is described as a '60 ft. bed of agglomerate near caves at the mouth' of the stream.

Fogo. R. 'Montindor', a stream just north of M. Almada, may equal R. Pico.
R. M. Grico and R. Ramajuda, probably R. de Traz and R. Helena respectively.
R. S. Filipe = R. do S. João.

S. Antão. R. de Morro Braz = R. da Tortalho.

II. Previous Work and General Geology of the Archipelago

Considering their nodal position on the South Atlantic trade routes the Cape Verde Islands seem to have attracted comparatively few geological visitors and it is only within the last twenty years that we have obtained anything like a general picture of the geology of the archipelago as a whole, thanks mainly to the work of J. B. Bebiano of the Portuguese Geological Survey. Prior to this we have been restricted to scraps of information collected during short calls by expeditions *en route* elsewhere, such as *Beagle* (1831–1836), *Challenger* (1873–1876), the German South-polar (*Gauss* 1901–1903) and the German Atlantic (*Meteor* 1921–1923), Shackleton–Rowett (*Quest* 1921–1923), and to the work of C. Doelter (1882) and I. Friedlaender (1913). W. Bergt contributed two chapters on the geology and petrology to Friedlaender's account of his visit to the islands, but gave few details of the material. The present author has described the *Quest* collection (1930) and H. Ermert certain sands and rocks collected by the German Atlantic *Meteor* Expedition (1936). R. Stahlecker (1935) has established the Neocomian age of the Lower Cretaceous cephalopod fauna of Maio, and a summary of other palaeontological research up to 1933 is contained in R. Furon (1935).[1]

In 1926 the Portuguese Ministry for the Colonies sent out a Geographical Commission to map the islands (apparently the first official maps to be made) and with them went Eng[ro] J. Bacelar Bebiano of the Geological Survey. After five years spent in what he terms a 'geological reconnaissance' his memoir *A geologia do Arquipélago de Cabo Verde* was published by the Geological Survey of Portugal in 1932—very appropriately 100 years after Charles Darwin's first visit to S. Tiago in H.M.S. *Beagle*. This memoir contains abundant notes on the distribution and petrology of the various rock-types found, a number of new analyses by A. Mário de Jesus, and an appendix by de Sousa Torres on the Miocene fauna of S. Tiago. More recently J. M. Cotelo Neiva has discussed some of the chemical aspects of Bebiano's work (1940).

General geology

The whole group of islands is of comparatively recent formation and there seems no ground for the legend handed down by a succession of continental writers that several of them are largely composed of Pre-Cambrian 'basal complex'. The earliest rocks so far established are the Lower Cretaceous of Maio. Furon (1935: 270) has put the matter in a nutshell: 'Du Primaire nous ne savons strictement rien. On pourrait peut-être lui attribuer certains des calcaires cristallins à mica et amphibole de l'île de Fogo, mais sans aucune autre raison que leur aspect ancien.' From these particular limestones Child has collected pebbles derived from the volcanic suite and I consider

[1] Dates and pages within parentheses refer to the list of publications on p. 35.

there is very little doubt that they represent locally metamorphosed sediments of Tertiary age.

During Eocene times the Neocomian limestones and grits of Maio were invaded by sheets of basalt and lamprophyre and subsequently steeply folded and eroded. On the surface so formed the rest of the island has grown and the general succession laid down by Bebiano (see below) seems to hold good, with minor local variations, all over the archipelago.

	Recent and Quaternary	Calcareous beach and dune sands. Basalts and ashes.	Stage IV
Tertiary	Late Tertiary	Basalt, alkali-basalt, and ashes. Phonolite, intrusions of Nepheline-Syenite, Nepheline-Monzonite, and Essexite.	Stage III
	Miocene	Conglomerates, clays, and limestones.	
	Early Middle Tertiary	Basalt and ashes ('Main basalt' series).	Stage II
	? Eocene	Earliest sills of Maio.	Stage I
Cretaceous	Post Aptian	? Maio. ? S. Tiago.	
	Aptian	Limestones of Maio.	
	Neocomian	Limestones and grits of Maio.	

The first eruptions produced a series of slightly alkaline olivine-basalts and ashes (Stage II). This 'Main basalt' series was followed by a period of erosion and subsidence during which a series of littoral and dune deposits, consisting of pebble-beds, clays, and calcareous sands, were laid down at some points round the coasts. The sands, formed of fragments of various organisms with minor amounts of volcanic detritus, are now consolidated into beds of limestone, frequently richly fossiliferous and in S. Tiago known to be of Miocene age. Renewal of volcanic activity brought more basalts and also types richer in soda: alkali-basalts of various types, phonolite, trachyte, and intrusions of nepheline-syenite, nepheline-monzonite, essexite, and allied types (Stage III). After a period of quiescence accompanied by elevation and erosion a final reversion to basic lavas brought the sequence to a close (Stage IV). These form the 'Recent' basalts of Bebiano. In several islands and notably in Sal, Maio, and Boa Vista there are extensive littoral and dune deposits of Pleistocene and Recent age similar in character to the earlier Miocene sediments. Fogo is still potentially active, and Friedlaender records an ash-shower as recently as 1909.

There are, of course, local variations on this general theme, e.g.:

S. Antão. This island does not seem to contain any representation of the Miocene sediments.

S. Vicente. Here the succession is (1) 'Main basalts'; (2) Mindelo and Saladinha volcanic series, mainly much-altered basalts accompanied by phonolite and alkaline intrusive types; (3) 'Recent' basalts. Sediments appear to be confined to the Pleistocene and Recent and there seems little reason to suppose that any of these are Mesozoic as suggested by Friedlaender.

S. Nicolao. (1) 'Main basalt' series; (2) Tertiary sediments, probably Miocene, but the rich fauna has not yet been worked out; (3) alkali-lavas of Stage III, including an area particularly rich in phonolite and trachyte dykes termed by Bebiano the 'Vila

complex' from the village of that name in the north of the island. The subsequent geological history of S. Nicolao has been one of volcanic tranquillity and of gradual elevation and erosion. There would seem to be no Stage IV lavas present.

S. Tiago. (1) Basalt; (2) Miocene sediments; (3) basalt, phonolite, and intrusions of alkali-rich types; (4) Pleistocene and Recent basalt and sediments. According to Bebiano, phonolite occurs in conglomerates below the limestones at Tarrafal in the north. These latter appear to be Upper Miocene in age, so that in this area eruption of phonolite must have started slightly earlier than elsewhere. Much of the limestone around Praia is undoubtedly Pleistocene or Recent in age, and is covered in some places by more recent limburgite lavas.

Bebiano notes that several areas marked 'basalt' on his map are probably 'Recent' limburgite and he records well-preserved craters at a number of places in the interior of the island.

Brava. According to Bebiano the succession here is (1) basalt; (2) phonolite and phonolite ashes, the last in very considerable quantity; (3) sediments. There seem to be no 'Recent' lavas, and since the ejection of (2) the island has been subject to intensive erosion. The basalts, mainly alkaline limburgites, contain inclusions of syenite, and inclusions of this and of basalt occur in the phonolite whilst pebbles of phonolite occur in the limestones.[1]

Fogo. Bebiano was not able to visit this personally, so as we have a considerable number of specimens among the Child Collection it is proposed to deal with this island in rather greater detail.

It is the newest geologically—nearly circular in shape, 26 × 24 km., and in form a stratified cone of lava and ash rising in the centre to 2,600 m. Most of the north-east central part is occupied by a huge caldera, 9 km. across and 1,000 m. deep, on its western side. The eastern side has been breached and from its floor rises a secondary cone, Pico (2,829 m.), the second highest mountain in Portuguese territory exceeded only by Mt. Ramelau (2,950 m.) in Timor. Round the northern and eastern base of Pico at about 1,600 m. are a number of parasitic vents from which have flowed the Recent lavas of Relva, Cova Martinho, and Bombardeiro between 1680 and 1857. On the south flank of the main cone are other Recent flows emitted prior to the Portuguese occupation in 1461. Fumaroles and deposits of mineral salts occur south-east of Pico and steam issues from a cavern at 2,800 m. Friedlaender records a small ash eruption in 1909.

Tectonics. Attention must be drawn to the marked linear distribution of the Windward group (S. Antão, S. Vicente, Sta Luiza, S. Nicolao, and Boa Vista). These lie along a WNW.–ESE. line which Bebiano suggests is a fault. He notes also the comparatively steep (1 in 20) submarine slope to the west of S. Antão, indicating a possible NE.–SW. fault cutting off the archipelago on the north-west side (Plate 4). I would add that the general structural grain of S. Antão is along NE.–SW. lines, so the possibility of a fault or fold axis running through the island in this direction should not be overlooked. There is also the possibility of a NE.–SW. fault separating

[1] It is the author's opinion that the real explanation of this succession is that all the igneous series are normal Stage III with a special development of phonolite and that the limestones are Recent in age. Bebiano records raised beaches and tufa deposits.

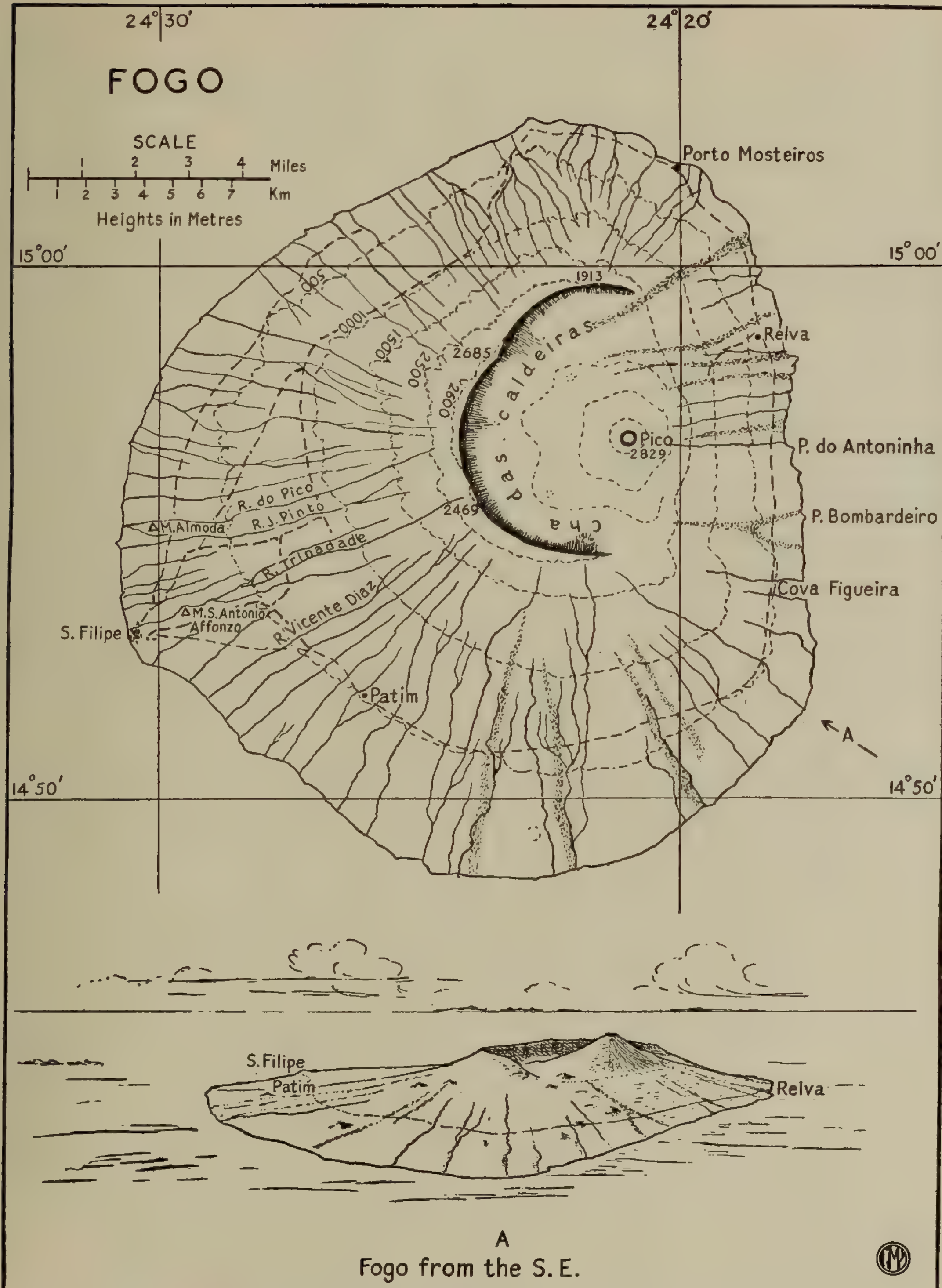


FIG. 1. Map of Fogo based on Portuguese Surveys

S. Antão from its neighbour S. Vicente. West of a line connecting Maio and Sal another steep slope (1 in 10) marks a fault-zone running roughly north to south through these two islands. Locally, and especially on the west side of Boa Vista, the Tertiary lavas have been converted into 'schists', thereby helping to perpetuate the 'basal complex' legend, to which reference has been made above.

Bebiano has put forward the idea that Fogo has arisen on a southerly prolongation of a north-to-south axis of folding which he has detected in the southern part of S. Nicolao. The map of the archipelago, and particularly the submarine contours, suggest that the structure of this southern part is based on a series of roughly parallel folds: (1) running SSE. from S. Nicolao through S. Tiago NW.–SE.; (2) a similar, though not so pronounced, fold NW.–SE. through Fogo.

The map of Fogo shows that the steepest slopes occur in the northern parts of the island (Fig. 1) and there is evidence of considerable recent elevation in the south-west in the presence of marine terraces at 150, 280, 350, and 500 m., all of which goes to strengthen the view that the whole cone has acquired a pronounced tilt to the north-east about a NW.–SE. axis. There is, further, some evidence for a progressive easterly shift of the centre of activity beginning with a mid-Tertiary centre in the neighbourhood of S. Filipe. The great caldera of the main cone is centred about a point on the western slope of Pico, whilst many of the secondary vents on the north and east sides are concentric with Pico itself. All Recent flows have broken out around the eastern base of this cone, approximately along the margin of the old crater ring, suggesting a further shift in the same easterly direction.

In the archipelago generally considerable elevation and erosion have taken place all through Pleistocene times resulting in the present wild and barren topography; in Bebiano's words, 'com desfiladeiros inaccessiveis, ravinos profundissimas de aspecto "dantesco"'.

Friedlaender (1913: 37) has suggested that the islands represent—geographically—a western extension of that Tertiary orogeny which gave rise, amongst much else, to the Atlas mountain system in North Africa. Bebiano has discussed the origin of the archipelago at some length and, rejecting the Wegener hypothesis of continental drift, concludes that while Friedlaender's suggestion may well apply to the initial late Cretaceous or early Tertiary folding and intrusions in the Cretaceous beds of Maio, the main factor has been isostatic crustal adjustment in a belt parallel to the coast following on the great accumulation of sediment in the seas bordering on West Africa during and since Tertiary times. He draws particular attention to the north-to-south fault controlling Sal, Boa Vista, and Maio and the system of NE.–SW. and NW.–SE. cross-faults and folds in the archipelago, notably that along which S. Nicolao and S. Vicente are situated. The original hypothesis of 'continental drift' has not gained much acceptance among geologists, who seem agreed that since Tertiary and possibly Mesozoic times the earth's crust has been too thick or too strengthened by folding to admit of drift, though the idea has more attraction as we get back to the Carboniferous. J. R. Chelikowsky (1944) has pointed out the mechanical principles involved in the hypothesis, which, expressed simply, consists in balancing the sinking Pacific area by splitting the land-mass opposite to it and moving the halves round the circumference. The fundamental difficulty is that the land-

mass in question—Africa—has been throughout most of its history since Pre-Cambrian one of the few relatively stable parts of the crust. But if the crust is too strong to drift it is not strong enough to resist fracture and in late Cretaceous or early Tertiary times there was initiated in East Africa a system of tensional cracks mainly N.–S. with NW.–SE. and NE.–SW. cross-faulting—the Great Rift Valley system extending from Palestine to the Rhodesias, accompanied by repeated volcanic episodes: Basalt (Eocene), basalt and phonolite (Miocene), and basalt again (Recent). This is precisely the sequence in both time and rock-type that we find in the Atlantic islands. Is it not possible that we have here a system of tensional cracks on the west side of the stable African block corresponding to the Great Rift on the east side? It is not improbable that all three factors—Atlas orogeny, tensional rift stress, and isostatic adjustment for sedimentary accumulation—have played a part in the tectonic history of the archipelago at different times.

List of the chief publications to which reference has been made

Bebiano, J. B. 1932. A geologia do Arquipélago de Cabo Verde. *Commun. Serv. Geol. Portug.* **18.**

Chelikowsky, J. R. 1944. A new idea on continental drift. *Amer. J. Sci.* **242:** 673–685.

Chevalier, A., & Furon, R. 1935. Sur quelques dépôts tertiaires et quaternaires des îles du Cap Vert. *C.R. Acad. Sci. Paris,* **201:** 226–227.

Darwin, C. R. 1844. *Geological observations on the volcanic islands visited during the voyage of H.M.S. 'Beagle'*, &c. London.

Doelter, C. 1882. *Die Vulcane der Capverden und ihre Producte.* Graz.

Ermert, H. 1936. Ein Beitrag zur Kenntnis der Gesteine der Kapverdischen Inseln São Vicente und Sal. *Chem. d. Erde,* **10:** 155–186.

Friedlaender, I. 1913. *Beiträge zur Kenntnis der Kapverdischen Inseln, &c.* Berlin.

—— 1914. *Subsídios para o conhecimento das Ilhas de Cabo Verde por Immanuel Friedlaender,* Trad. portuguesa de Garcia Guerreiro. Lisboa.

Furon, R. 1935. Notes sur la paléogéographie de l'Océan Atlantique. 1. La géologie des îles du Cap Vert. *Bull. Mus. Hist. nat. Paris,* (2) **7:** 270–274.

Harker, A. 1907. Notes on the rocks of the 'Beagle' Collection. I. *Geol. Mag., Lond.* N.S. **4:** 100–106.

—— 1935. *Petrology for Students.* 7th edit. Cambridge.

Jesus, A. Mário de. 1932. Subsídios para a petrologia do Arquipélago de Cabo Verde. (Ilha de S. Vicente). *Commun. Serv. Geol. Portug.* **17:** 86–103. (For 1931.)

Lacroix, A. 1934. Mission au Tibesti. *Mém. Acad. Sci., Paris.* **61:** 169–369, 20 pls., 2 maps.

Neiva, J. M. Cotelo. 1940. Considerações sôbre o quimismo das formações eruptivas do Arquipélago de Cabo Verde. *Publ. Mus. e Lab. Min. e Geol. Pôrto* **17.**

Part, G. M. 1930. Report on the rocks collected from St. Vincent, Cape Verde Islands. *Report on Geol. Collections made during voyage of 'Quest'*, Chap. 11. London: Brit. Mus. (Nat. Hist.).

—— 1946. An augitite from S. Vicente, Cape Verde Islands. *Geol. Mag., Lond.* **83:** 241–242.

Reinisch, R. 1912. Gesteine der Atlantischen Inseln, &c. *Deutsche Südpolar-Exped.* ('*Gauss*'), *1901–3*, **2** (7): 641–662.

Renard, A. F. 1889. Rocks of the Cape Verde Islands. 'Challenger' Reports, Physics and Chemistry, *Rep. Sci. Res. Voy. 'Challenger'*, **2** (7): 13–23.

Smith, W. Campbell. 1938. Petrographic description of volcanic rocks from Turkana, Kenya Colony. *Quart. J. Geol. Soc. Lond.* **94:** 507–553.

Spiess, F. 1932. Das Forschungsschiff (Meteor) und seine Reise. (Lotungen zwischen Kapverdischen Inseln und Festland.) *Deutsche atlantische Expedition* (*Meteor*) *1925–1927. Wiss. Ergeb.* **1:** Kartenbeilage 16.

Stahlecker, R. 1935. Neocom auf der Kapverden-Insel Maio. *Neues Jahrb. Min. Geol. Paläont.* Abt. B., Beil. Bd. **73:** 265–301.

III. Petrology of the Volcanic Rocks

(*a*) *Phonolites*

The Child Collection includes examples of a great variety of these rocks from the six islands visited by him. As might be expected from the nature of this collection, many are stream- and beach-pebbles, loose boulders and pieces from blocks out of agglomerates, but they serve to illustrate the astonishing variety in composition and texture shown by this group of rocks as developed in the Cape Verde Islands, where the term 'phonolite' clearly covers much more than its usual text-book definition as the 'volcanic equivalent of the nepheline-syenites'. In the present case it obviously also includes the extrusive versions of the nepheline-monzonites and a variety of residual alkaline fractions separated off from a variety of partial magmas as well. In his description of S. Antão, Bebiano records numerous examples of what he terms 'andesite with feldspathoid'—rocks containing a variety of plagioclase feldspars in addition to, or to the exclusion of, potash-feldspar, which further study would probably reclassify as trachyandesites and basic phonolites.

There are a number of specimens in the Child Collection from S. Antão and S. Nicolao ('Vila Complex') which are difficult to classify and which require closer petrological and chemical study as well as more detailed knowledge of their occurrence and associates. They combine features of the phonolites, tephrites, and trachybasalts and appear to be comparable to several varieties found in East Africa.

The time is not considered ripe for a detailed re-examination of the phonolite group as a whole, and in the ensuing description only a mineralogical classification employing such terms as 'hornblende-' or 'haüyne-phonolite' will be used.

The majority of these rocks are fine-grained, pale grey, green, or buff in colour speckled with phenocrysts of haüyne, nepheline, aegirine-augite, and, in certain types, of sanidine. These phenocrysts rarely exceed 1–3 mm. in size. A number of specimens, mainly from the agglomerates, are coarse 'clots'—sanidinite or haüynite—composed of crystal aggregates with little or no groundmass, similar in character to the well-known sanidinite of the Eifel (Fig. 5*a*).

Minerals

Haüyne. Most varieties contain euhedral phenocrysts, often abundant, of some member of the sodalite group. In the majority this is, or has been, haüyne, though the characteristic blue colour is uncommon and in many instances the mineral has been replaced by sundry secondary products, analcime, nepheline, calcite, feldspar, or zeolites.[1] Sodalite, often turbid, occurs in some of the phonolites. A. Harker (1907: 106) records sodalite as forming numerous little dodecahedra, turbid in the interior, in a phonolite from S. Tiago [CD. 4709].[2]

[1] Bebiano has recorded nosean in addition to haüyne in phonolites from S. Antão (op. cit.: 69) and this mineral is seen in sections of phonolite from Brava [27], and from Fogo [807]. W. C. S.

[2] Numbers in square brackets, [ ], are those under which specimens are listed in the catalogues of the Departments in which they are housed. Simple numbers of one to three figures, e.g. [520], refer to the Child Collection (B.M. 1915, 130). The prefix 'Q' refers to *Quest* Expedition specimens (B.M. 1927, 1245). 'C' and 'CD' numbers are those of the Department of Mineralogy and Petrology, Cambridge Collections ('CD' belonging to the Darwin *Beagle* Collection).

Nepheline. Mostly present in euhedral crystals of the usual form in both phenocrysts and groundmass; alteration products include calcite, cancrinite, feldspar, and zeolites. Refractive index measurements indicate that in some cases examined, kaliophilite may be present in solid solution in amounts up to 20 per cent.

Leucite. In certain of the Brava specimens the groundmass contains small rounded or subhedral crystals with low R.I. and extremely weak birefringence quite distinct in appearance to the haüyne present in the rock, and characterized by concentric zones of inclusions. These appear to be leucite.

Feldspar. The normal feldspar of these rocks is sanidine which in many, if not in most, cases must contain appreciable amounts of albite in solid solution, and in some of the phonolites from S. Tiago zonary banding exhibited under crossed nicols suggests rhythmic variations in soda-content during crystallization.

Pyroxene. The usual pyroxene of the phenocrysts is a green aegirine-augite with well-marked pleochroism, X yellow $<$ Y green $<$ Z grass-green, and $Z \wedge c$ varying in different examples from 57° to 68°, but generally about 63° (cf. Harker, 1907: 106). Crystal form is usually good, though the outer skin, which is commonly of a darker green and approaching aegirine ($X \wedge c$ 0–7°), may be replaced by a zone of ragged aegirine grains. The pyroxene of the groundmass is a similar aegirine and tends towards ragged or acicular shape.

Amphibole. Both brown and green hornblendes occur, but except in the glassy rocks or where enclosed within other phenocrysts they are nearly always partially replaced by granular aggregates of green aegirine-augite. In the hornblende-melanite-phonolites of S. Tiago the amphibole is a dark green variety (X yellow $<$ Y dark olive $<$ Z dark laurel, often virtually opaque). In addition to the usual reaction rim of pyroxene grains[1] it has another form of alteration to magnetite which spreads along the cleavages and eventually replaces most of the crystal. Measurement of extinction is difficult owing to the absorption, but is high, of the order of 25°.[2]

Biotite. This is an important minor constituent in the Brava specimens and has been an early formed mineral in other centres but has rarely survived ([C. 4710 = CD. 108], north of Praia, S. Tiago), being always more or less replaced by deep corrosion borders of aegirine-augite granules except in the ashes or in pumice. The replacement seems to have taken place at a very early stage in crystallization because whereas the normal pyroxene in the groundmass of these rocks is an aegirine with $X \wedge c$ small, the extinction $Z \wedge c$ of the grains forming the reaction rims of the biotite is about 60°, lower even than that of the normal phenocrysts (63°).

Sphene is of general occurrence in typical lozenge-shaped crystals 0·1–0·25 mm., exceptionally up to 1–2 mm. ([103], 'Minhoto' = Covoada, Brava), less commonly in irregular grains.

Apatite occurs in all the phonolites in the usual hexagonal prisms and needles. In some of the xenoliths and 'clots' it is intimately associated with haüyne and reaches a size of 0·5 mm. in cross-section.

[1] Described by A. Harker, 1907: 106.

[2] Doelter had an analysis made of hornblende phenocrysts in a phonolite from Monte Batalha, Maio. These are described as brown, strongly pleochroic, with extinction angles ranging up to 15°. The results of the analysis by F. Kertscher gave: SiO_2 39·96, Al_2O_3 16·91, Fe_2O_3 3·42, FeO 8·86, CaO 15·94, MgO 6·03, Na_2O 9·01. Total 100·13. (C. Doelter, *Die Vulcane der Capverden und ihre Producte*, 1882: 96.)

Magnetite is another regular component in octahedra or irregular grains of 0·1–0·5 mm. and in smaller crystals and grains disseminated in the groundmass.

Melanite is an occasional accessory usually in dark brown dodecahedra with marked zonary banding. In the Praia area (S. Tiago) it is a regular constituent in phenocrysts up to 1 mm. across, its outer zones often replaced by pyroxene granules.

Analcime, calcite, cancrinite, haematite, and zeolites occur filling vesicles and as late-stage and secondary replacement minerals. Bebiano (p. 35) records the development in the groundmass of the phonolites of M. Cavallo, S. Vicente of small spherulites of kaolinized feldspar. This kind of replacement is well shown in Child's specimens from the same area ([733, 741], west slope, M. Verde), but must be regarded as replacement by zeolites.[1] In the hand-specimen and even under the microscope, using ordinary light, these show all the appearance of typical fresh phonolites with phenocrysts of nepheline [W. C. S.] and of a sodalite mineral (0·5–1·0 mm.) in a fine ground of sanidine laths, euhedral nepheline, and acicular aegirine, but polarized light reveals the replacement of most of the light constituents by aggregates of zeolites.

Textures

These rocks vary from glassy or pumiceous to coarse types composed mainly of phenocrysts. Taking them as a whole they exhibit a remarkable diversity of appearance in thin-section. Having a general tendency to idiomorphism among the principal components—haüyne, nepheline, feldspar, and pyroxene (or amphibole)—their micro-textures are mainly controlled by the crystal-habit and relative sizes and proportions in which these minerals occur in the phenocrysts and groundmass. Superimposed on these are other differences due to mode of formation and environment (vitreous, fluxional, and vesicular textures), to changes in chemical equilibrium during or after consolidation (such as the replacement of hornblende by pyroxene), or to the effects of late solutions (bringing in analcime, calcite, zeolites, or secondary feldspar).

Description of typical examples

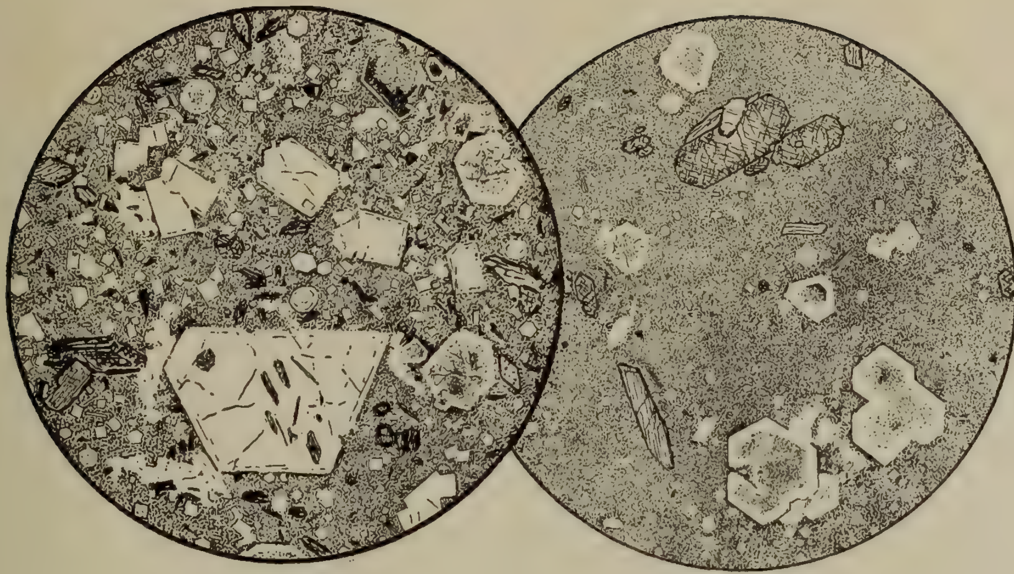
A few of the principal types encountered are described below.

Leucite-phonolite

[52], near Pedrinha, Brava—is a crumbly cream-coloured pumice containing haüyne (0·5–1·0 mm.), flakes of fresh biotite, rounded sanidine, and occasional small aegirine-augites in an almost colourless glass (R.I. 1·517) crowded with small leucites up to 0·025 mm. in diameter, and scattered small crystals of sphene.

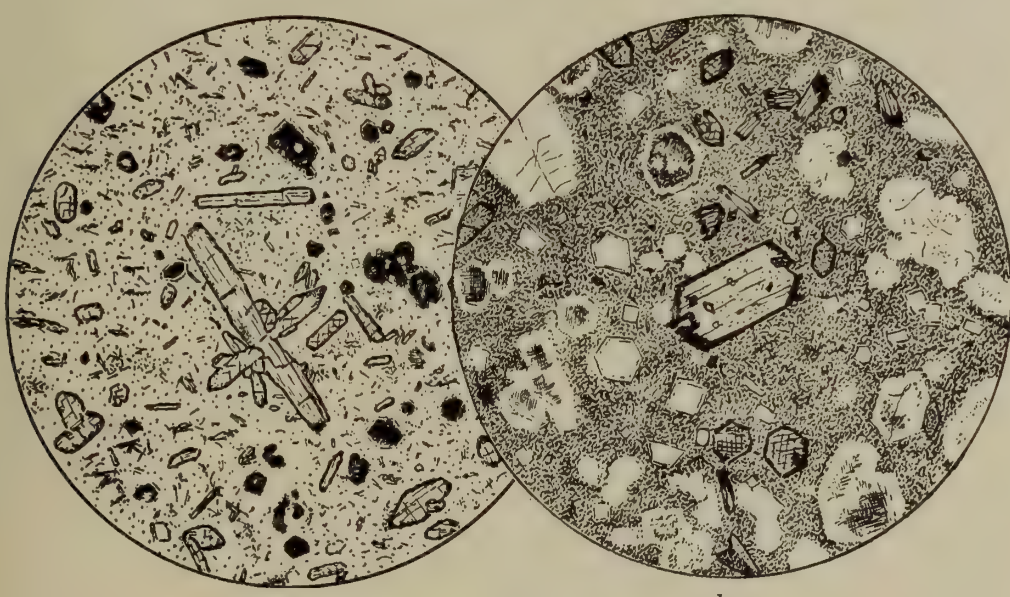
[163], above Fonte Vinagre, Brava—a typical example of 'seriate' texture with the larger haüyne, nepheline, and pyroxene crystals ranging up to 1 mm. as do a few of the sphenes, though the majority of these are much smaller. The aegirine-augite phenocrysts have R.I. α 1·708, γ 1·727, $Z \wedge c$ 63°, and 2V 73°, positive. They have an outer shell of ragged aegirine. The refractive index of the nepheline (ω 1·535, ϵ 1·540) indicates a content of nearly 20 per cent. kaliophilite. The base is a pale yellow glass which in addition to euhedral nepheline, haüyne, aegirine-augite, and ragged aegirine granules contains small leucites and a few sanidine laths up to 0·1 mm. A certain

[1] This kind of replacement by zeolites has been described from several other regions, e.g. Nyasaland. See Dixey, Smith, and Bissett, *Bull. Geol. Surv. Nyasaland*, no. 5, 1937: 56.



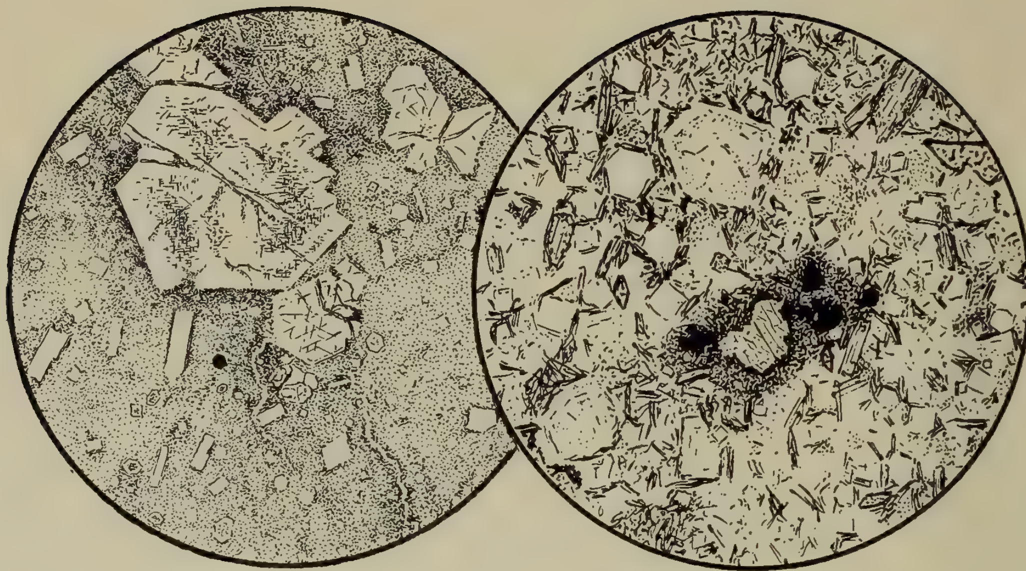
a *b*

FIG. 2. Leucite-phonolites. (*a*) Fonte Vinagre, Brava [163]. (*b*) S. of 'Povoação' Church, Brava [122]



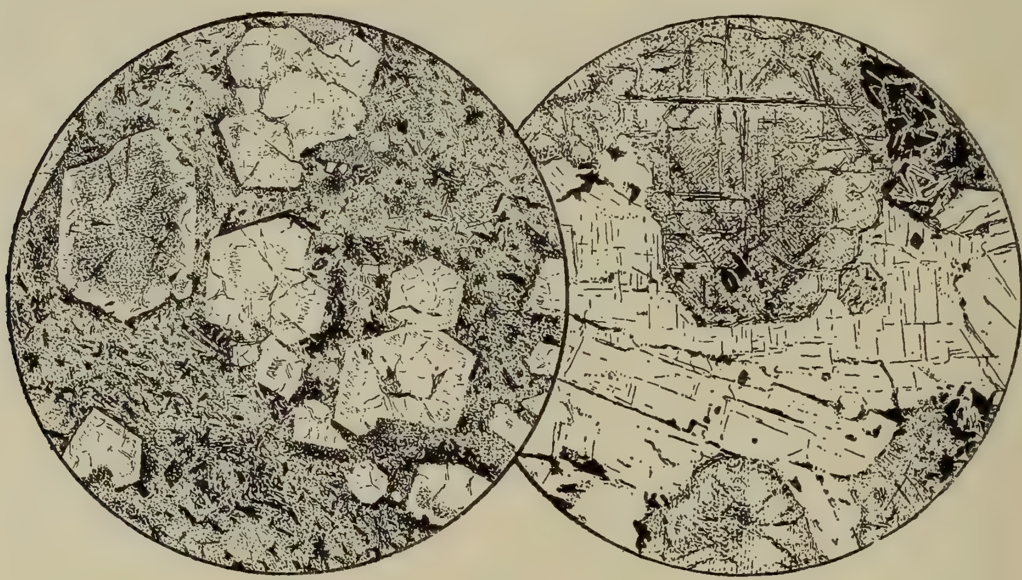
a *b*

FIG. 3. Haüyne-phonolites. (*a*) R. Trinadade, Fogo [807]. (*b*) 'Minhoto', Brava [102]



a *b*

FIG. 4. Haüyne-phonolites. (*a*) S. of 'Povoação' Church, Brava [131]. (*b*) E. cliff, Tarrafal, S. Antão [574]



a *b*

FIG. 5. (*a*) Haüyne-phonolite. $1\frac{1}{2}$ km. S. of Furna, Brava [27]. (*b*) Haüyne-sanidinite. Agglomerate, R. 'Lacacan', Brava [71]

amount of what appears to be finely divided calcite is scattered through the base and small vesicles are filled by analcime (Fig. 2*a* and Table I, column 2).

The other figured specimen [122] from ¾ km. south of Povoação Church, Brava (Fig. 2*b*), has a more fine-grained groundmass than [163]. Small 'leucite' crystals are very abundant.

Haüyne-phonolite

[27], 1½ km. south of Furna, Brava (Child has 'miles' in his list, but this must be wrong; the locality lies about half-way between Furna and Fonte Vinagre). The porphyritic elements make up 25·5 per cent. (haüyne 16·5 per cent., sanidine 3 per cent., aegirine-augite 1·5 per cent., sphene 0·5 per cent.). Haüyne reaches 0·5–1·5 mm., the rarer sanidine 1·0 mm. The base is composed of small nephelines (0·05 mm.), sanidines up to 0·1 mm. in length, and acicular aegirine (0·1 mm.). Small areas of granular pyroxene represent altered biotite and, like the pyroxene of the phenocrysts, has $Z \wedge c$ 60°. (Fig. 5*a* and Table I, column 1.)

Very similar to the above is [85], from R. 'Lacacan' agglomerates, notable for the bright blue colour of its haüyne. Another feature of this type is the 'clotting' of the pyroxene granules of the base into strings and patches and the concentration of these tangentially round the haüyne phenocrysts. I suggest that this textural feature is not entirely due to flow, but rather to pressure exerted by rapid growth of the haüyne phenocrysts throughout their period of crystallization. A similar texture has been noted in phonolites from Kenya (Campbell Smith, 1938).

Two specimens from Fogo, almost identical, and probably from the same flow, come from 5 km. up R. Trinadade [807] and 2½ km. up R. 'S. Filipe' [824]. Both are pale sage-green in colour, rough-textured, but fine-grained and without obvious phenocrysts in the hand specimen. Microscopically they show abundant little aegirine-augites (0·25–1·0 mm.) having $Z \wedge c$ 65° and smaller haüynes (up to 0·25 mm.) and nosean. Their groundmass is very fine-grained and is composed of euhedral nepheline, ragged acicular aegirine ($X \wedge c$ small), occasional grains of magnetite, and apatite needles enclosed in poecilitic plates of feldspar up to 0·25 mm. across, which appear to be of a soda-potash variety (see Table I, column 3).

[824] is rather finer in grain than [807] and has a small quantity of pale yellowish glass in its groundmass.

A type with abundant plates of biotite [8] comes from north of the harbour at Furna. Phenocrysts make up 12 per cent. of the rock and consist of haüyne in euhedra 0·5–2·0 mm. replaced by cloudy decomposition products (4 per cent.), well-formed aegirine-augite, up to 2 mm., with $Z \wedge c$ 63° and outer skin of aegirine (5 per cent.), magnetite 1·5 per cent., and biotite 1·5 per cent. This last occurs in rounded and corroded plates up to 2 mm. across, each with an almost opaque border of granular aegirine-augite ($Z \wedge c$ 60°). Sphene and apatite both occur in comparatively large crystals, 1 mm. or over; in the body of the rock the apatites are rounded but well-shaped hexagonal prisms up to 0·5 mm. across and occur packed in calcite-filled vesicles. The groundmass (76 per cent.) is composed of euhedral nepheline and needles of aegirine (0·05 mm.) enclosed in plates of potash-feldspar, mostly a microperthite. There are also a few scattered grains of magnetite and melanite both of very small

TABLE I

	1	*2*	*3*	*4*	*5*	*6*	*7*
SiO_2	51·16	46·95	49·81	53·76	54·18	56·22	47·63
Al_2O_3	21·53	18·98	20·76	22·18	21·52	22·74	18·94
Fe_2O_3	2·64	3·64	2·92	1·33	1·93	0·84	1·47
FeO	1·86	1·47	1·80	2·53	1·74	2·71	8·12
MnO	0·07	0·15	0·13	0·09	0·08	0·26	0·28
MgO	0·68	0·79	0·99	0·15	0·76	0·76	3·52
CaO	1·92	5·34	4·65	2·10	2·61	1·94	6·94
Na_2O	10·53	9·39	8·95	8·74	4·14	6·07	5·85
K_2O	5·69	5·93	6·19	5·96	4·27	3·13	3·71
TiO_2	0·49	0·63	1·10	0·39	0·68	0·56	2·56
P_2O_5	0·05	0·14	0·23	tr.	0·08	0·04	0·64
CO_2	tr.	1·66	0·21	tr.	—	tr.	0·15
Cl	0·34	0·31	n.d.	0·37	0·15	0·09	0·18
SO_3	1·14	0·19	0·35	0·18	0·06	0·26	0·27
H_2O+	1·72	2·89	0·76	2·01	4·36	3·34	0·03
H_2O-	0·45	1·69	0·23	0·24	3·30	1·16	0·04
Totals	100·27	100·15	99·08	100·03	99·86	100·12	100·33
Less O for Cl.	0·08	0·07	—	0·08	0·03	0·02	0·04
Net Totals	100·19	100·08	99·08	99·95	99·83	100·10	100·29

NORMS

or	33·92	31·14	36·70	35·58	25·58	18·35	21·68
ab	16·77	—	7·34	21·48	33·01	48·73	14·67
an	0·28	—	—	5·84	11·95	9·45	17·09
ne	33·23	34·93	35·22	26·13	—	—	16·04
lc	—	3·05	—	—	—	—	—
hl	0·59	0·59	—	0·59	0·23	0·15	0·29
th	1·99	0·43	0·57	0·43	0·14	0·57	0·57
nc	—	—	—	—	—	—	0·37
ac	—	9·70	0·92	—	—	—	—
wo	1·28	2·44	5·34	—	—	—	—
hy	—	—	—	—	2·43	5·73	—
di	4·91	7·41	5·40	4·14	—	—	11·43
ol	—	—	—	0·97	—	—	9·74
mt	3·71	0·46	3·02	1·86	2·78	1·16	2·09
hm	—	—	0·48	—	—	—	—
il	0·91	1·22	2·13	0·76	1·37	1·06	4·86
ap	—	0·34	0·67	—	0·34	—	1·34
Q	—	—	—	—	8·40	3·84	—
C	—	—	—	—	6·22	6·43	—

1. Haüyne-phonolite, I(II).7.(6)7.1.4. 1½ km. south of Furna, Brava. [B.M. 1915, 130, (27).]
2. Leucite-phonolite, II.7.1.″4. Above Fonte Vinagre, Brava. [B.M. 1915, 130, (163).]
3. Haüyne-phonolite, ″II.7.1.4. 5 km. up R. Trinadade, Fogo. [B.M. 1915, 130, (807).]
4. Hornblende-phonolite, I.″6.1″.4. M. S. Pedro, 5 km. north of Praia, S. Tiago. [B.M. 1915, 130, (202*a*).]
5. Hornblende-trachyte, I″.″5.2.3″. Rio Brava valley, Vila, S. Nicolao. [B.M. 1915, 130, (324).]
6. Hornblende-trachyte, I″.5.2.4. R. da Tôrre, S. Antão. [B.M. 1915, 130, (520).]
7. Tahitite, II.6.2″.4. From east cliff, 600–800 ft., Tarrafal, S. Antão. [B.M. 1915, 130, (542).]

Analyses by W. H. Herdsman, except No. 3, which is by Geochemical Laboratories, Wembley, London.

size. Vesicles are of two kinds, one more or less circular and filled by calcite, the other ramifying irregularly through the groundmass into which they merge at their edges, and composed of zeolites and potash-soda feldspar (Fig. 6*a*).

Bebiano (op. cit.: 205) records a phonolite containing biotite along with haüyne and sphene at M. Vizia, 200 metres west of Furna, Brava, with large phenocrysts of

FIG. 6. (*a*) Biotite-rich haüyne-phonolite. N. of Furna, Brava [8]. (*b*) Hornblende-trachyte. R. da Tôrre, S. Antão [520]

feldspar in a groundmass of microlites of aegirine-augite, nepheline, and orthoclase, with biotite, haüyne, and sphene. The feldspar is said to include oligoclase.

Blocks in the phonolite agglomerate. The 'blocks' and 'clots' of rocks resembling the sanidinites of the Eifel district referred to above (p. 36) are from the phonolite agglomerates of Brava, Child's description of the locality being 'cliffs near cave at mouth of Rio Lacacan'. Several of the specimens are haüyne-sanidinites, containing 'clots' mainly of haüyne with reticulated inclusions of iron ores usually in zones, and variable amounts of sanidine with or without a little albite-oligoclase. The interstices between these crystals are filled with phonolitic base or nests of aegirine needles, iron ore, and glass. [71, 72.]

[67], from the same locality, is another coarse 'clot' composed of aegirine-augite, magnetite, haüyne, biotite (in parts mainly replaced by magnetite), and apatite. The finer parts of the specimen are composed mainly of haüyne with scattered ragged pyroxenes. These minerals enclose poecilitically a mesh of apatite prisms, which in the coarser portions occurs also in radiating tufts (Fig. 7*a*). The pyroxene has R.I. α 1·727, γ 1·745.

[115] from the phonolite tuffs, 1 km. west of 'Povoação', Brava, is a 'clot' of

medium grain composed of haüyne, aegirine-augite, biotite, and sphene enclosed in poecilitic plates of nepheline, whilst in [739], a phonolite occurring on the west slopes of M. Verde, S. Vicente, there is a small 'clot' composed of coarse haüyne and aegirine-augite enclosed poecilitically in plates of golden-brown sphene.

Other combinations which have been noted are titanaugite, and titanaugite and hornblende ([5] south of Furna, Brava). Similar coarse 'clots' are found in the Recent lava-field south-west of Carvoeiros, S. Antão.[1] A typical specimen is [484], a coarse mosaic of ragged interlocking hornblendes and pale greenish augite, some of the crystals reaching a length of 1·5 cm. The hornblende is strongly pleochroic in shades of yellow, golden-brown, and dark chestnut-brown. The margins are almost opaque and merge into zones of magnetite at the edges separating the crystals. In places there is a little pale, rather cloudy, glass (Fig. 7*b*).

Hornblende-phonolite

This appears to be of frequent occurrence in S. Tiago, S. Nicolao, and S. Antão. Bebiano records phonolites carrying amphibole in all these three islands. The Darwin specimens from S. Tiago [C. 4715, 33912] have been described by A. Harker (1907: 106)[2] and Child's specimens from the same area resemble these. Nos. 202*a* and *b* from M. S. Pedro, 5 km. north of Praia, S. Tiago, may be regarded as typical. Streaming and fluxional textures are common in these phonolites (Fig. 8*a*). The groundmass is a very fine felt of sanidine laths 0·05–0·1 mm., ragged acicular aegirine of similar size, and small nephelines of about 0·025 mm. Magnetite is scarce.

Sanidine and nepheline form phenocrysts up to 4 mm. in length and there are smaller phenocrysts of hornblende, 0·5–2 mm., and abundant green pyroxene and melanite (0·25–1 mm.) and small, turbid sodalites up to 0·25 mm. in diameter.

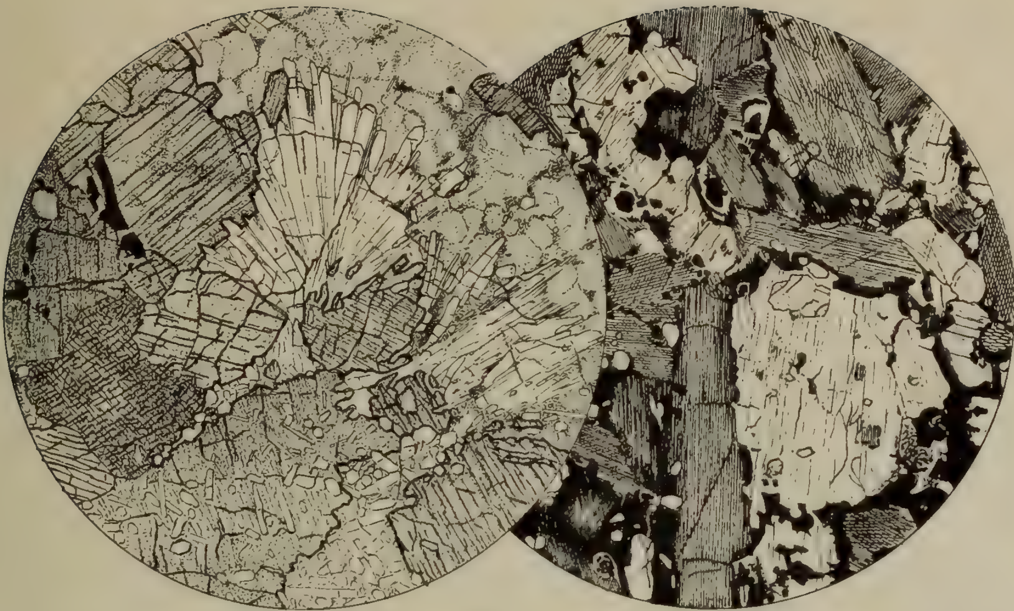
The sanidine phenocrysts range up to 4 mm. in length, but many of them are bent or broken and recemented by zeolites, calcite, or new feldspar. Most of them have an outer skin of new sanidine and zonary banding is common under crossed nicols. Refractive indices of both sanidine and nepheline show that these carry considerable amounts of their alkaline opposite number in solution:

	Nepheline		*Deduced % Kaliophilite*	*Sanidine*		*Deduced % albite*
	ω	ϵ		α	γ	
202*a*	1·543	1·538	22	1·522	1·528	40
202*b*	1·538	1·533	16	1·521	1·527	37
CD. 165	1·537	1·532	15	1·520	1·526	34
CD. 107	—	—	—	1·519	1·525	31

CD. 165 }
CD. 107 } NW. of Praia, S. Tiago

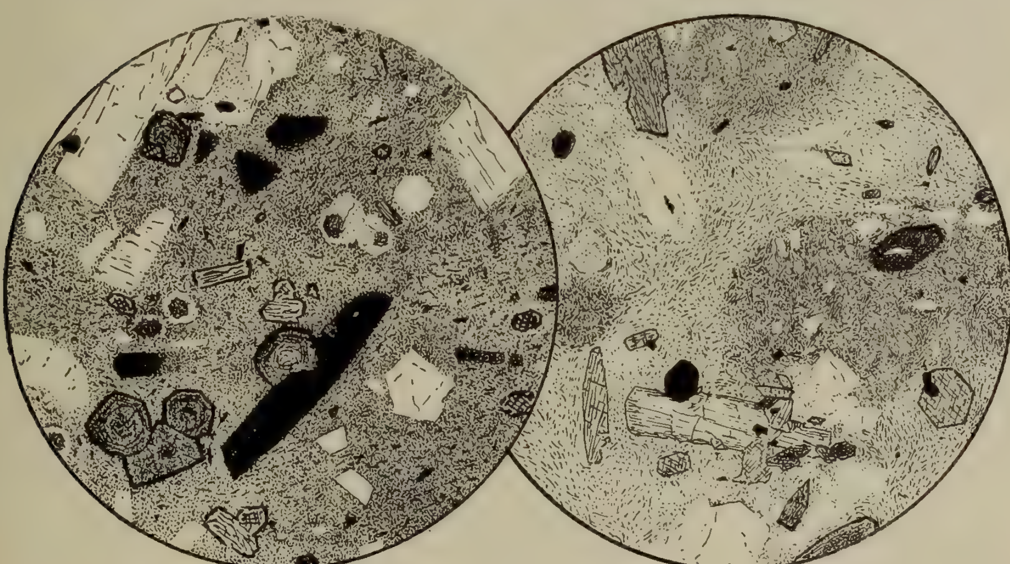
[1] Doelter (1882: 149) has described similar aggregates from S. Antão. The rocks with which they are associated appear to be predominantly basalts with some limburgites and nephelinites. See also *Quest* Report, 1930: 75. W. C. S.

[2] Doelter (1882: 95) distinguished between augite-phonolites and hornblende-phonolites. Harker has remarked (1907: 106) that if, as seems likely, pyroxene is due to resorption of hornblende, this distinction marks no very essential difference. The hornblende-bearing phonolites are listed together here for convenience of description. Doelter records them as more frequent than augite-bearing phonolites in Maio but not numerous in other islands of the group.



a *b*

FIG. 7. (*a*) Apatite-aegirine augite-haüyne 'clot'. Agglomerate, R. 'Lacacan', Brava [67].
(*b*) Hornblende-pyroxene 'clot'. Lava-field SW. of Carvoeiros, S. Antão [484]



a *b*

FIG. 8. (*a*) Hornblende-phonolite. M. S. Pedro, S. Tiago [202*b*]. (*b*) Hornblende-trachyte.
Rio Brava, Vila, S. Nicolao [324]

Modal analysis of phenocrysts gave the following results:

	202a	*202b*	*C. 4715*	*C. 33912*
Sanidine . . .	13·2	16·2	11·8	11·1
Nepheline . . .	6·0	8·6	8·2	7·8
Sodalite . . .	3·2	3·5	4·2	3·7
Aegirine-augite . .	1·5	3·3	2·1	5·4
Hornblende . .	3·1	3·5	3·6	—
Melanite . . .	2·5	2·3	1·2	3·2
Totals . . .	29·5	37·4	31·1	31·2

202*a* }
202*b* } M. S. Pedro, 5 km. north of Praia, S. Tiago.
C. 4715 (CD. 164) N. by E. of Praia, S. Tiago.
C. 33912 (CD. 86) 2 m. west of Quail Island ('an islet in the bay of Porto Praya', C. Darwin, 1844: 3).

A chemical analysis of 202*a* is given in Table I, column 4.

(*b*) *Leucitophyre and Haüynophyre*

Haüyne-leucitite. [803], 2 km. up R. Trinadade, Fogo, a rough-textured finely vesicular, sage-green rock, shows under the microscope numerous small phenocrysts of elongated aegirine-augite (0·1–0·5 mm.), moderately pleochroic in green and yellow and with $Z \wedge c$ 63–66°. Rare phenocrysts up to several millimetres in length are of a brown hornblende ($Z \wedge c$ 7°) and the other constituents of this phase are irregular grains of magnetite and blue haüyne (0·1–0·25 mm.). The last are partly euhedral, partly rounded, or skeletal. The groundmass consists of a mass of small euhedral leucites and acicular aegirine-augites (both from 0·06 mm. down) with occasional haüyne, magnetite, and apatite in a base partly of euhedral nepheline and partly of colourless glass. Sanidine is inconspicuous and is either entirely absent or present in very small amount. Vesicles are very numerous and irregular in shape (Fig. 10*a*).[1]

Tahitite. [542, 544] '600–800 feet, east cliff, Tarrafal, S. Antão.' An unusual and interesting type is represented by specimens of a black, aphanitic rock with resinous to glassy lustre with drawn-out spindle-shaped, steam cavities. Under the microscope it is seen to consist of a dark brown glass, almost opaque except in the thinnest sections, crowded with elongated microlites and needles of brown augite and minute grains of magnetite. There are a few scattered phenocrysts of brown augite and brown hornblende (0·2–1·0 mm.), the latter pleochroic from X pale straw yellow $<$ Y brown $<$ Z brown, $Z \wedge c$ small not exceeding 5–7°. The corresponding angle for the augite is 52°, with slightly higher values for the microlites of the base. The most striking feature of the rock is the numerous little phenocrysts (about 0·1 mm.) of haüyne, colourless in their centres, but each with a marginal zone of bright sky-blue.

The rock may best be classed as a somewhat basic Tahitite and an analysis is given

[1] This rock compares fairly well with rocks described by R. Brauns as leucitophyre from the Laacher See district in Germany (R. Brauns, *Neues Jahrb.* 1922, Beilage-Band, **46:** 31–34). Hornblende has not been observed in thin sections and is evidently extremely rare. The rock is definitely leucocratic and its affinities are with the phonolites rather than the nephelinites, and for these reasons it has been included with the 'tahitite' in this appendix to the phonolites. W. C. S.

in Table I, column 7, which may be compared with that of tahitite from Papenoo valley, Tahiti.[1]

(c) *Trachytes*

Certain rocks of 'phonolitic' aspect from S. Antão and S. Nicolao are best classed as trachytes. Examples of these are [324] Rio Brava valley, Vila, S. Nicolao (Fig. 8*b*), [520] R. da Tôrre, 3 km. from the shore, S. Antão (Fig. 6*b*), and [580] east cliff, Tarrafal, S. Antão. These rocks differ from the phonolites with which they are associated in their relatively high silica content (Table I, columns 5 and 6), the absence or unimportance of feldspathoids, and the abundance and variety of their feldspar phenocrysts. These not infrequently present 'xenocrystal' features such as cores, H-shaped in section, of older feldspar on which the phenocryst has grown; this in turn may have suffered further corrosion and have an outer shell of newer sanidine in optical continuity with the core and partly separated from it by a narrow zone of glass. Cases have been observed of sanidine moulded on cores of plagioclase, of plagioclase terminations on sanidine cores with a final skin of sanidine, [520, 524, 536] R. da Tôrre and [580] Tarrafal, and in these there are also some curious 'cornsheaf' phenocrysts composed of radiating bundles of crystals arranged at angles up to about 36° either side of the principal axis of the group.

Pyroxene is similar to the pale green aegirine-augite of the phonolites, but in a few exceptions has a pale purplish tinge with or without greenish margins and with extinctions $Z \wedge c$ between 50° and 60°.

Amphiboles—brown hornblende, X straw-yellow $<$ Y brown $<$ Z chestnut-brown occurs in two generations, that of the phenocrysts having $Z \wedge c$ 8° and the microlites of the base 15–18° ([524] Tarrafal, S. Antão). In [324, 339] Vila complex, S. Nicolao, both brown and green forms occur, the first having $Z \wedge c$ 15° and the second extinction and pleochroism similar to that of the S. Tiago phonolites. [520] Tarrafal, S. Antão, has a bluish-green amphibole in addition to the brown and green varieties.

Textures are mostly very fine-grained, trachytic or pilotaxitic, composed of narrow microlites of sanidine (0·1 mm.) and aegirine-augites. In some there is a little pale glass and small irregular vesicles filled with either glass or analcime, and the presence of subordinate nepheline in others links them with the phonolites. In the spotted forms the spots do not appear to differ materially from the rest of the rock. They may be slightly richer in pyroxene, but seem to derive their darker colour from a general cloudiness of the feldspar and from a yellowish colour in the glass.

[1] This rock bears a close resemblance in hand-specimen and in thin section to the tahitite described by Prof. A. Lacroix from Papenoo valley, Tahiti, in 1910. Lacroix originally described it as haüynophyre, but 'dans la nomenclature minéralogique . . . comme une augitite à haüyne . . .' (*Bull. Soc. Géol. France*, 1910, ser. 4, **10**: 113–114), and mentions among comparable rocks a haüynophyre from S. Antão described by Doelter (1882: 121). In this paper Lacroix published an analysis of the rock by Pisani which was listed in H. S. Washington's 'Chemical Analyses of Igneous Rocks' (*U.S.G.S., Prof. Paper 99*, 1917: 572).

A *corrected analysis* was published by Lacroix in 1917 (*C.R. Acad. Sci. Paris*, 1917, **164**: 584) and the name *tahitite* was given. In his *Minéralogie de Madagascar* (1923, **3**: 29) Lacroix quotes the corrected analysis, but on p. 286 of the same volume the original figures are given, and they appear again in a paper by Lacroix on the islands of Southern Polynesia in 1928 (*Mém. Acad. Sci. Fr.*, 1928, **109**, no. 2: 18). Happily, Johannsen (*Petrography of the Igneous Rocks*, 1938, **4**: 189) quotes the corrected analysis.

W. C. S.

The chemical composition of these trachytes is shown in Table I, columns 5 and 6. One may note, compared with the phonolites, their relatively higher silica, alumina, and ferrous iron and lower values for ferric iron, lime, and alkalies.[1] Two further examples of this division, [342] and [321], S. Nicolao, are illustrated (Fig. 9). The first is composed of a felt of potash feldspar with much fine interstitial granular pyroxene and abundant iron ore grains, but without prominent phenocrysts. The second is more porphyritic and fine in grain with rare phenocrysts of brownish-green

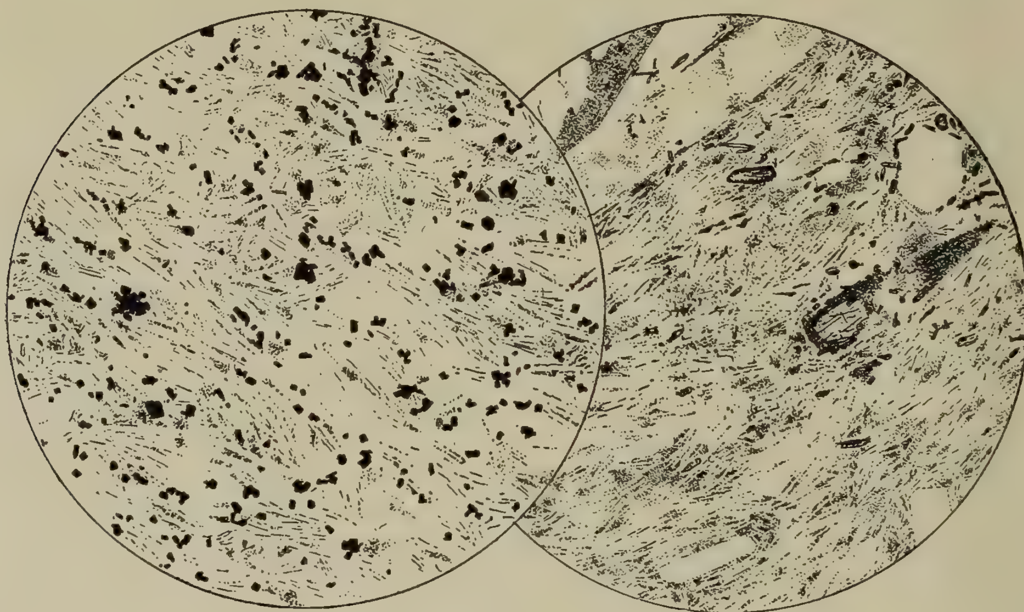


FIG. 9. Trachytes. (*a*) Prainha, S. Nicolao [342]. (*b*) Rio Brava valley, S. Nicolao [321]

amphibole partly or entirely altered to granular pyroxene, and occasional areas which appear to represent feldspathoid. The base is fine-pilotaxitic with ragged laths of green pyroxene dispersed among the feldspars.

(*d*) *Tephrites and Basanites*

[563] from the east cliff at Tarrafal, S. Antão, is a tephrite containing xenocrysts of brown hornblende. An analysis of the rock is given in Table II, column 1. In hand-specimen it is a dark grey, fissile, and rather crumbly rock with phenocrysts of pale augite (0·5–1·0 mm.) and magnetite (up to 0·5 mm.) in a fine ground of similar augite, magnetite, and plagioclase laths (0·05–0·1 mm.) with accessory apatite and rare flakes of biotite. The ultimate base is of nepheline and analcime. The augite appears to be a sodic variety with high extinction around 55° rising to 62° in the outer zones. Feldspar shows an extreme composition of An_{57}, but most of it is about An_{27}. The

[1] Another notable feature of these analyses is a very high water content. This appears to be attributable to abundant analcime in amygdules and probably also in the groundmass. W. C. S.

chief interest of the rock is the presence of broken and corroded xenocrysts of brown hornblende ($Z \wedge c$ 5–7°) up to 2 mm., and more rarely of biotite. The mode of alteration takes the form of a felt of pyroxene grains, flakes of biotite, and vermicular growths composed of scales of a dark mineral pleochroic in shades of reddish-brown and greyish-green. The pleochroism and extinction ($Z \wedge c$ about 40°) agrees with rhönite.

A considerable proportion of the lavas forming the main cone of Fogo would appear to conform fairly closely to the rock from Patim described by Bebiano as *basalto nefelínico* (*basanito*) (1932: 199), being black or dark grey, vesicular, and usually very fine-grained and rich in phenocrysts of titanaugite, olivine, and magnetite in a base which is partly isotropic and partly of poecilitic plates of labradorite (An_{65-50}) with a little nepheline. One's first inclination is to assume that the isotropic portion is analcime, but all the available analyses show insufficient water to form more than an insignificant amount of this, so that the bulk of the isotropic base must be regarded as glass. Typical of these rocks is [813] from the R. Ramajuda, of which the above is a brief description. Certain of these lavas [812, 779] are rich in large phenocrysts of titanaugite and olivine up to several millimetres in length in a base similar to that described above, but dense with magnetite and pyroxene. [812] from R. João Pinto, for instance, has 43·5 per cent. phenocrysts made up of euhedral titanaugite 26·4 per cent., euhedral olivine 12·0 per cent., both up to 4–5 mm., and rounded magnetites (0·5 mm.) 5·1 per cent. Refractive indices of augite and olivine show:

	α	γ	Fa	$Z \wedge c$
Olivine . . .	1·667	1·706	Fa%15	—
Titanaugite core .	1·697	1·721	—	53°
Titanaugite skin .	—	1·725	—	57°

(Fig. 10*b*). An analysis of this rock is given in Table II, column 2.[1]

[779] from R. Trinadade is similar to those described above in texture and appearance but contains less olivine. Titanaugite is abundant (0·5–1·0 mm.), sometimes reaching 2·5–3 mm. and often arranged in stellate groups. Magnetite occurs in irregular groups of octahedra up to 0·5 mm. across and the fine-grained groundmass is composed of augite and magnetite in a base similar to that in the previous examples (analyses, Table II, column 5).

The Recent lavas of Viana crater, S. Vicente, described in the *Quest* Report are very similar in character to the finer grained examples from Fogo, but in most cases are rather more glassy and scoriaceous. [Q.A12] showed a few patches of nepheline in the groundmass (Part, 1930: 122).

[1] I have added for comparison (Table II, column 3) the analysis of the *basanitóide* described by Bebiano (1932: 26) and in greater detail by A. Mário de Jesus (1932: 95 and fig. 7). The rock carries conspicuous phenocrysts of olivine and augite in a groundmass of microlites of augite and plagioclase and grains of magnetite. Nepheline was not observed.

The analysis by Raoult (Table II, column 4) of the basanite described by Bebiano from 'Povoação do Patim', referred to above shows much higher Al_2O_3 and lower MgO. One result of this is that no *ol* appears in the norm, though according to the description the rock contains 'olivine in small anhedral crystals altered to iron oxide'. According to the description the groundmass is partly isotropic and contains nepheline and analcime, microlites of augite and feldspar, and magnetite. W. C. S.

TABLE II

	1	*2*	*3*	*4*	*5*
SiO_2	43·67	42·53	43·58	42·18	42·08
Al_2O_3	17·58	9·48	9·99	14·01	15·03
Fe_2O_3	4·91	3·22	2·56	4·58	3·25
FeO	7·08	10·66	8·78	8·28	8·68
MnO	0·27	0·24	0·13	0·13	0·33
MgO	5·77	11·56	11·50	5·90	5·52
CaO	10·58	14·83	13·36	13·16	12·74
Na_2O	4·62	2·22	2·28	3·69	4·16
K_2O	1·14	1·02	1·71	2·26	2·84
TiO_2	2·56	4·02	3·97	5·06	4·24
P_2O_5	0·69	0·21	1·33	0·82	0·77
CO_2	tr.	0·15	—	—	nil
Cl	—	—	0·06	—	—
SO_3	—	—	—	—	—
H_2O+	0·84	tr.	1·14	0·21	0·08
H_2O-	0·16	0·13	0·34	0·10	0·16
Totals	99·87	100·27	100·73	100·38	99·88
Less O for Cl.	—	—	0·01	—	—
Net Totals	99·87	100·27	100·72	100·38	99·88

NORMS

or	6·7	0·5	10·0	13·3	3·89
ab	14·3	—	4·7	—	—
an	23·9	12·5	11·9	14·7	13·62
ne	13·4	10·2	7·9	17·0	19·31
lc	—	4·8	—	—	10·03
wo	—	—	—	—	—
di	19·4	46·8	36·3	36·0	35·75
ol	7·4	12·2	13·6	0·7	2·42
cs	—	—	—	—	—
mt	7·2	4·7	3·5	6·7	4·64
il	4·9	7·6	7·6	9·7	8·06
hm	—	—	—	—	—
ap	1·7	0·5	3·1	2·0	2·02
hl	—	—	—	—	—
cc	—	(0·3)	—	—	—

1. Hornblende-tephrite, ″III.6.3.4(5). East cliff, Tarrafal, S. Antão. [B.M.1915, 130, 563.] Anal. W. H. Herdsman.
2. Nepheline-basanite, III.6.3.4. R. João Pinto, Fogo. [B.M. 1915, 130, 812]. Anal. W. H. Herdsman.
3. 'Basanitóide', 2,200 m. N. 40° W. from Monte Madeiral, S. Vicente, at no. 8 km. on the Mindelo–Viana road. (III)IV.6.3.″4. A. Mário de Jesus, 1932: 97. Anal. A. Mário de Jesus.
4. Nepheline-basanite, III.(7)8.(2)3.4. Patim, Fogo. Bebiano 1932: 199. Anal. Raoult.
5. Tephrite, III.7(8).2″.4. R. Trinadade, Fogo. [B.M. 1915, 130, 779.] Anal. W. H. Herdsman.

A slate-grey rock with scattered phenocrysts of olivine, up to 3 mm. across, in an aphanitic groundmass is from 3 km. west of Carvoeiros, S. Antão [398]. The base consisting partly of analcime and partly of laths and poecilitic plates of labradorite (An_{70-85}) averaging about 0·1 mm. across, with augite microlites up to 1 mm. in length and abundant magnetite grains. This type I have termed analcime-basanite.

(e) *Nephelinites*

As examples of nephelinites and olivine-nephelinites (nepheline-basalts)[1] specimens of several types from Fogo, S. Nicolao, and S. Antão are described below. Doelter has described them from S. Tiago and S. Vicente as well (op. cit.: 118–130).

[831] from the cliffs south of S. Filipe, Fogo, is somewhat similar in general appearance to the other Recent lavas (of the area, nepheline-basanites [779, 813], described above (p. 49), but is finer in grain, none of its crystals exceeding 0·5 mm. It differs from the others in lacking feldspar and may be classed as nephelinite.

[800], 4 km. up R. Trinadade, Fogo, is a brownish granular olivine-nephelinite containing abundant black pyroxenes up to 5 or 6 mm. in size. The microscope shows numerous hypidiomorphic violet-brown titanaugite, 3–6 mm. moderately pleochroic, and with R.I. α 1·712, γ 1·730–1·735, $Z \wedge c$ 53° (core), 58° (margin), the margins being greenish in parts. The groundmass is a mixture of the same titanaugite, olivine, magnetite, nepheline, and apatite. As nepheline is in general idiomorphic towards pyroxene, the edges of the latter are usually ragged and the phenocrysts are in consequence only very roughly idiomorphic. The olivine occurs in rounded or subhedral grains with only slight serpentinization or iron-staining at the margins, R.I. 1·675, γ 1·712 (Fa_{20}). Nepheline is in the form of a granular mosaic of more or less euhedral crystals with scattered interstitial patches of leucite, some of which have been replaced by a fine fibrous intergrowth apparently composed by microperthite. This has a 'marbled' texture under crossed nicols reminiscent of the 'pseudo-leucite' described by various authors from intrusive rocks supposed to have contained leucite. The general grain-size of all the constituents of the groundmass is 0·25–0·5 mm. with occasional crystals running up to 0·75 mm. The mode of the rocks is approximately—Titanaugite 33 per cent. (phenocrysts 24 per cent.), Olivine 5 per cent., Magnetite 12 per cent., Nepheline 37 per cent., 'leucite' (including 4 per cent. feldspathic alteration) 11 per cent., Apatite 1 per cent. (Fig. 11*a*).

This rock is notable for the unusually large grain-size. The earlier writers would perhaps have called it a 'nepheline-dolerite'. There is unfortunately no information available as to its mode of occurrence, but it may be suggested that it comes either from the interior of a thick flow which has supplied [799, 806] or from a sill of similar composition intercalated in the lavas.

An example of leucite-nephelinite comes from between 4 and 5 km. up R. Trinadade, Fogo [799, 806]. The analysed and figured specimen (806, Table III, col. 1; Fig. 11*b*) is a black, slightly vesicular lava containing numerous black iridescent augites up to 1 cm. in length and small white spots of about 1 mm. diameter. The phenocrysts are of the usual brown titanaugite (α 1·713, γ 1·737, $Z \wedge c$ 57°), euhedral nepheline (the white spots in the hand-specimen), and very rare grains of olivine (0·25 mm.). The groundmass is seriate in texture composed of euhedral titanaugite, nepheline, magnetite, and small inconspicuous leucites.

Harker figured (1935: 202) as 'nepheline-basalt' a similar rock from Fogo.

[1] Apart from its colloquial use as a general term for basic lavas it does not seem good practice to employ 'basalt' in compound names for rocks devoid of feldspar, so for these I shall use 'nephelinite', 'leucitite', and 'analcimite' with such mineral prefix as may be appropriate. G. M. P. [See Report of the Committee on Petrographic Nomenclature, *Min. Mag.*, 1921, **19**: 142.]

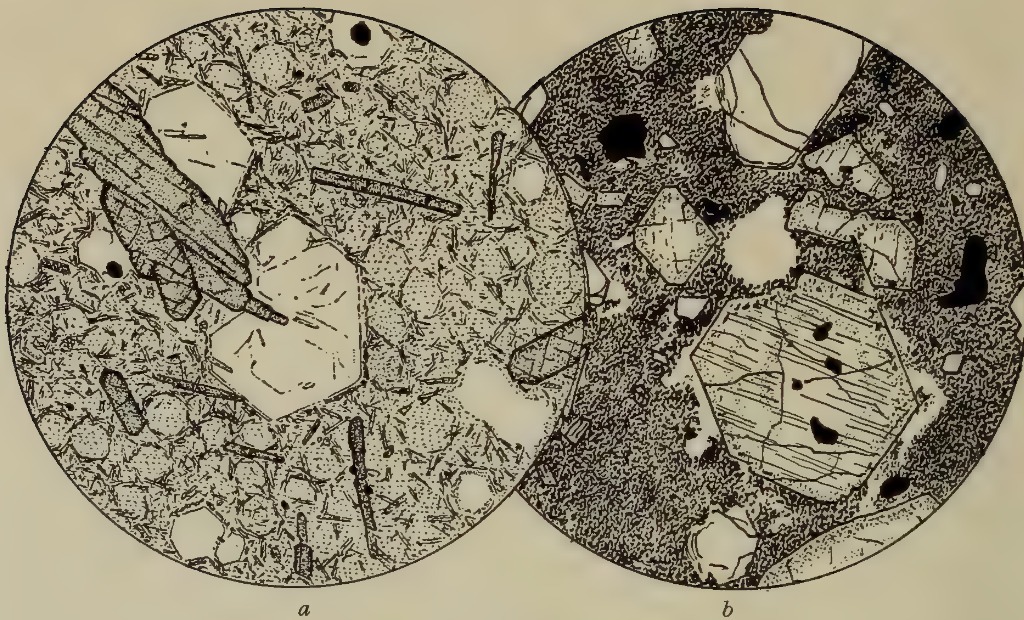


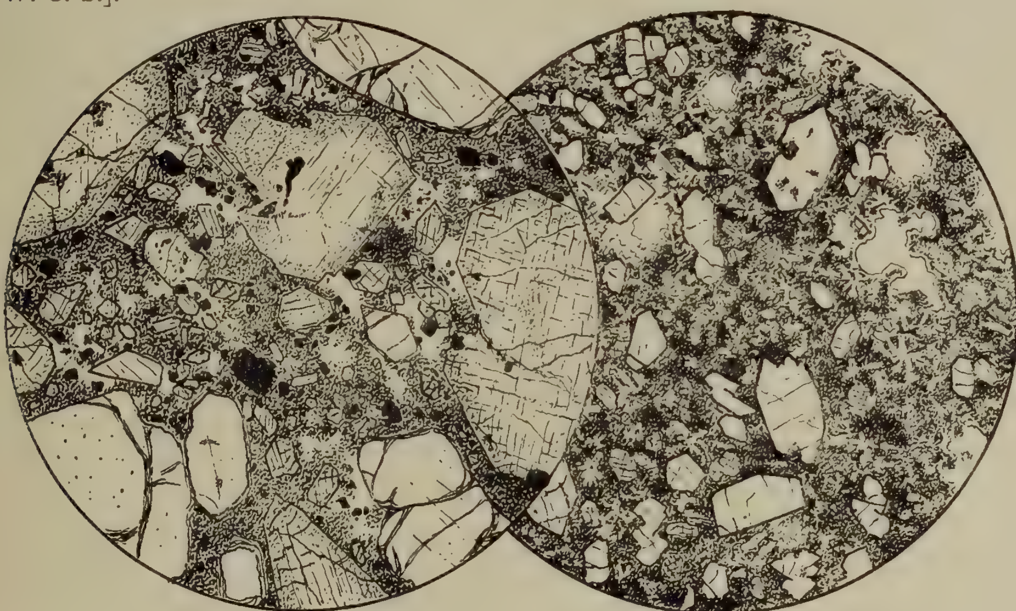
FIG. 10. (*a*) Haüyne-leucitite [Leucitophyre]. R. Trinadade, Fogo [803]. (*b*) Nepheline-basanite. R. João Pinto, Fogo [812]

FIG. 11. Leucite-nephelinites. (*a*) R. Trinadade, Fogo [800]. (*b*) R. Trinadade, Fogo [806]

[216], M. S. Pedro, 5 km. north of Praia, S. Tiago, is a moderately coarse rock with a seriate texture. The large pyroxene and olivine phenocrysts range up to 6–7 mm., the pyroxenes euhedral, the olivines rounded or subhedral. Magnetite is common in all sizes up to 1·5 mm. and accessories are apatite and occasional flakes of biotite. Optical data for the olivine and pyroxene are as follows:

	α	γ	Fa	$Z \wedge c$
Olivine	1·665	1·704	Fa%15	—
Titanaugite	1·708	1·736–9	—	54–57°

Olivine is chiefly concentrated in the phenocrysts, whilst the finer portions consist mainly of pyroxene and magnetite in a base composed of turbid analcime (Fig. 12*a*). The analysis (Table III, column 2) compares with that of a nepheline-ankaratrite from 1 km., S. 30° W. of M. Amargosa, S. Vicente (M. de Jesus in Bebiano, 1932: 255) [in which also Bebiano (op. cit.: 26) doubtfully records analcime in the groundmass. W. C. S.].



a *b*

FIG. 12. (*a*) Olivine-nephelinite (analcitized). M. S. Pedro, S. Tiago [216]. (*b*) Limburgite. Praia, S. Tiago [C. 3898]

[391], Rio Brava valley above Vila, S. Nicolao, is a scoriaceous lava rich in phenocrysts of augite and olivine (0·25–1·0 mm.). The olivine is entirely replaced by pseudomorphs in calcite and haematite. The groundmass, fine-grained and highly vesicular, contains much magnetite and haematite and numerous little augites in all sizes up to 0·1 mm. The base is analcime, but much of this is possibly secondary, as the shapes of many small areas suggest that idiomorphic nephelines were originally present. The augite has a greenish colour and high extinction of the order of 60°, and

TABLE III

	1	2	3	4	5	6	7
SiO_2 . . .	41·52	40·16	39·13	37·38	36·77	36·16	37·86
Al_2O_3 . . .	15·24	10·34	10·20	18·03	9·80	6·85	4·37
Fe_2O_3 . . .	3·99	5·18	4·40	8·61	3·79	6·27	5·14
FeO . . .	6·27	8·44	8·93	3·22	7·89	6·94	9·00
MnO . . .	0·21	0·15	0·15	0·26	0·14	n.d.	n.d.
MgO . . .	5·07	11·58	12·72	8·04	14·94	13·88	22·78
CaO . . .	11·17	13·20	13·03	12·42	15·67	18·88	13·62
Na_2O . . .	5·68	2·37	3·32	3·68	2·49	2·65	1·53
K_2O . . .	3·73	0·66	0·61	1·51	0·97	1·00	1·02
TiO_2 . . .	3·89	4·56	4·98	2·57	4·07	4·61	3·38
P_2O_5 . . .	1·20	0·38	0·77	1·49	1·40	0·79	0·29
CO_2 . . .	nil	nil	0·52	tr.	—	—	—
Cl . . .	n.d.	0·38	0·02	n.d.	0·06	—	—
SO_3 . . .	n.d.	nil	—	n.d.	—	—	—
H_2O+ . . .	0·56	2·12	1·10	1·34	1·87	2·07	1·19
H_2O- . . .	0·26	0·32	0·26	1·19	0·39	0·36	—
Totals . .	98·79	99·84	100·14	99·74	100·25	100·46	100·18
Less O for Cl .	—	—	—	—	0·01	—	—
Net Total . .	98·79	99·84	100·14	99·74	100·24	100·46	100·18

NORMS

	1	2	3	4	5	6	7
or . . .	3·9	3·9	3·3	3·9	—	—	—
ab . . .	—	4·2	1·0	—	—	—	—
an . . .	5·0	16·7	11·4	27·8	12·8	3·6	2·2
ne . . .	26·1	7·4	14·5	17·0	11·1	12·2	6·8
lc . . .	13·9	—	—	3·9	4·8	4·8	4·8
wo . . .	0·9	—	—	—	—	—	—
di . . .	32·4	36·3	35·3	18·4	19·9	26·1	21·9
ol . . .	—	11·1	14·5	8·1	23·5	15·8	37·7
cs . . .	—	—	—	—	9·5	15·8	11·0
mt . . .	4·9	7·7	6·5	3·5	5·6	8·8	7·4
il . . .	7·6	8·7	9·6	5·0	7·7	8·8	6·5
hm . . .	—	—	—	6·2	—	0·2	—
ap . . .	2·7	1·0	2·0	3·7	3·4	2·0	0·7
hl . . .	—	0·6	—	—	0·1	—	—
cc . . .	—	—	(1·20)	—	—	—	—

1. Leucite-nephelinite, III.8″.1(2).2. 3 km. up R. Trinadade, Fogo. [B.M. 1915, 130, 806]. Anal. Geochemical Laboratory. [Summation low.]

2. Olivine-nephelinite, (III)IV.[6.3″.4″.]2.2.2.2. M. S. Pedro, 5 km. north of Praia, S. Tiago. [B.M. 1915, 130, 216]. Anal. W. H. Herdsman.

3. Nepheline-ankaratrite, IV.[7.3.″5.]2.2.2.2. 1 km. south, 30° W. of M. Amargoso, S. Vicente. A. Mário de Jesus, 1932:95. Anal. A. Mário de Jesus.

4. Melilite-nephelinite, III.(6)7.3′.4. East cliff, Tarrafal, S. Antão. [B.M. 1915, 130, 555]. Anal. W. H. Herdsman.

5. Ankaratrite melilítica, IV.[7.3.4.]2.3(4)2″.2. At 1,000 m. N. 15° W. from the survey mark of M. Verde, S. Vicente. A. Mário de Jesus, 1932: 90 = Basalto melilítico, Bebiano, p. 27. Anal. A. Mário de Jesus.

6. Ankaratrite très péridotique, mélilitique. Maio. IV.[8′.2.4.]2.3.′3.2. Anal. Raoult. Lacroix, *Min. de Madagascar*, 1923, **3:** 64.

7. Ankaratrite très péridotique, mélilitique. Sal. IV(V).[8.2.4]′2.′4.2.′2. Anal. Raoult. Lacroix, loc. cit.

is not far removed from the aegirine-augite of the associated phonolites. The numerous vesicles are filled centrally by calcite, with analcime and, more rarely, a fibrous zeolite at the edges.

[348], east slope, Alta Caramujo, S. Nicolao, is olivine-nephelinite, with accessory analcime in its base. The numerous olivine and rare titanaugite phenocrysts average about 0·25 mm. and lie in a fine base of idiomorphic titanaugite, nepheline, magnetite, and olivine grains enclosed in analcime and interstitial nepheline. The olivines are rounded and embayed and in the margins replaced by orange iddingsite. Analcime, some feebly anisotropic, fills the numerous small vesicles.

[555], east cliff, Tarrafal, S. Antão, is a slightly greenish-brown slaggy lava containing abundant black augites and shows under the microscope violet-brown titanaugite up to 5 mm. or over in length, often forming glomero-porphyritic or stellate groups. Other phenocrysts are of olivine (0·5–1·0 mm.), nepheline (0·5 mm.), and magnetite (0·25 mm.), the larger magnetites and nephelines also being usually composite groups. In addition there are a number of rectangular areas up to 0·5 mm. in size, composed of a pale yellow isotropic substance containing inclusions of apatite needles and showing in places traces of striation. This I believe represents melilite. The groundmass is composed of idiomorphic nepheline, augite, magnetite, and apatite, all approximately 0·1 mm., together with grains of olivine, irregular pink-brown perovskite (0·05 mm.), and a little interstitial nepheline.

Olivine is fairly fresh internally, but the outer zones are stained a deep chocolate-brown, apparently due to dust inclusions. It has α 1·667, γ 1·705 (Fa_{16}). The titanaugite has α 1·714, γ 1·735, $Z \wedge c$ 54°.

The vesicles are large, numerous, and irregular in shape, this latter feature controlled mainly by the deposition of the pyroxene phenocrysts.

An analysis of this rock is given in Table III, column 4.

A specimen, apparently a small block from the phonolite agglomerates of Brava [62], was collected on the north slope above R. da Vinagre (R. 'Lacacan'). It contains several basic patches, but the main part of the 'block' consists of idiomorphic aegirine-augite, nepheline, haüyne, and melanite-garnet, with occasional grains of apatite and sphene, in all sizes from 1 mm. downwards. The base is in general very fine in grain and composed mainly of pyroxene grains and dodecahedra of melanite in an isotropic ground apparently of haüyne, but the grain-size is very variable throughout. There are some veins and patches filled with calcite. In the slices examined there are two xenoliths, one of very fine recrystallized basic material probably originally one of the 'basalts', the other a coarse 'clot' composed of aegirine-augite, red-brown biotite, and magnetite.

An analysis by W. H. Herdsman gave: SiO_2 38·94, Al_2O_3 13·64, Fe_2O_3 6·44, FeO 4·81, MnO 0·34, MgO 3·88, CaO 15·79, Na_2O 1·98, K_2O 1·69, TiO_2 3·95, P_2O_5 1·23, CO_2 tr., Cl 0·07, SO_3 0·24, H_2O+ 4·51, H_2O- 3·00, total 100·51.[1]

[1] It is difficult to correlate this analysis showing high H_2O and only a trace of CO_2 with the specimen described. In the thin section seen by me some of the phenocrysts identified as haüyne are partly altered to calcite, and small patches of the surface of the specimen effervesce briskly with dilute HCl. The high water-content of the analysis suggests that the mineral identified as haüyne and the isotropic base might be analcime. My sections show occasional rounded flakes of biotite, some rather doubtful perovskite, and small patches of yellow altered melilite. W. C. S.

(*f*) *Melilite-basalt-tuff*

B.M. 1919, 161 (11), collected by Dr. D. A. Bannerman from M. Verde, S. Vicente, is a tuff made up of coarse fragments of rocks resembling the 'basalto melilítico' of M. Verde described by Bebiano (1932: 27). The material is vesicular, glassy, and scoriaceous with phenocrysts of olivine and greenish-brown augite, the latter less common than the olivine. The base is largely glassy, containing much augite and crowded with small elongated rectangular melilites mainly represented by a yellow material similar to that found in [555] and showing the common 'peg-structure'. Magnetite is disseminated all through the rock partly in the base, partly concentrated in the olivines. A few crystals, chocolate-brown to reddish-brown in colour, and often showing hexagonal outlines, are probably one of the sodalite group. Some fragments in the tuff show abundant small nephelines.

A 'melilite basalt' from Monte Verde described by Bebiano is further described by A. Mário de Jesus (1932: 89 and fig. 3) as 'ankaratrite melilítica'. It differs from the rock described above in that the olivine occurs abundantly as phenocrysts, those of augite being rare. The analysis of this rock by A. Mário de Jesus is included in Table III, column 5.[1]

(*g*) *Olivine-basalts*

Olivine-basalts play a dominant role in the geology of the archipelago. Bebiano estimates that basaltic lavas and ashes occupy 83 per cent. of the area of the islands. Child's collection contains many samples, but there is little or no information about their field relations and it is not possible for me to place them in their proper positions in the volcanic sequence (p. 31). I have therefore limited my observations on the basalts (with two exceptions) to those collected on S. Vicente, from which island there are representatives of basalts from Stages II, III, and IV.

The Recent (Stage IV) lavas of Viana crater on S. Vicente were described by me in the *Quest* Report (1930: 121). They are all black scoriaceous types, weathering rusty brown, and consisting in the main of a dark brown glass charged with minute brown augites, octahedral and skeletal magnetite, and a few ragged microlites of labradorite partly replaced by analcime. One of these [Q.A18] is figured in Fig. 13*b*, reproduced from the *Quest* Report (1930, fig. 22).

To Recent lavas must also belong the specimen [B.M. 39845] described as 'from an island which rose from the sea near the Cape Verde Is. and sank four hours later', and acquired by the Museum by purchase in 1865. No further details are known about the specimen other than the above description on its label, but the eruption in question is probably connected with the activity which took place in Fogo around the middle of the last century, the eruptions of 1847 and 1852 being of particular violence. It is possible that it may be associated with the submerged 'peak' shown on the map north-east of S. Vicente, the tip of which is shown in Portuguese soundings as lying at a depth of only 87 m.

[1] Lacroix published two analyses of melilitic olivine-rich ankaratrites by M. Raoult in *Minéralogie de Madagascar* (1923, **3:** 64) from Maio and Sal. In the text these were credited to the Canary Islands, but the mistake was corrected in the list of errata. The analyses are quoted in Table III, columns 6 and 7.

The rock is dark grey, highly vesicular, with scattered phenocrysts of plagioclase, pale titanaugite, and olivine up to 2 mm. in size and of rather smaller irregular magnetite. The plagioclase is a labradorite An_{65} with the usual more acid skin and the fine-grained groundmass is composed of plagioclase laths, granular pyroxene, occasional grains of olivine, magnetite, and a little almost colourless glass. The feldspar shows a certain amount of streaming particularly round the vesicles.

Stage III lavas on S. Vicente are represented by the Mindelo and Saladinha series (p. 31). These two local developments from east and south-east of Mindelo are

a *b*

FIG. 13. (*a*) Olivine-basalt. Hayden's Retreat, Mindelo, S. Vicente [Q.A29].
(*b*) Limburgitic basalt. Viana crater, S. Vicente [Q.A18]

characterized by richness in secondary minerals, chiefly calcite, which make up 70–80 per cent. of the rocks. Associated with them are carbonate dikes almost wholly made up of calcite (see Bebiano, 1932: 38).

To these series must be ascribed some highly altered lavas and ashes from points along the road from Mindelo to Matto Inglez. All the specimens examined, such as [712, 714], consist almost entirely of calcite and haematite, but enough of the original textures remain to show that the rocks were vesicular olivine-basalts very similar to those of the 'Main basalt' series already described. In [712] the vesicles are filled with calcite and zeolites such as natrolite, with some analcime.

The majority of the basalts from S. Vicente in Child's collection are olivine-rich basalts. These belong to the 'Main basalt' series (Stage II). Bebiano divides this series (1932: 24) into olivine-poor and olivine-free basalt; olivine-rich basalts (oceanites); and alkaline basalts. The olivine-rich basalts are the most abundant of the three. I believe Bebiano to be in error in describing these rocks as 'oceanites'. The large and numerous olivine phenocrysts give them the appearance of being rich in this mineral, but careful measurement on an integrating stage reveals that olivine

amounts to less than 20 per cent. of the total volume, with pyroxene not only in excess but usually greatly in excess of olivine.

Under the microscope these rocks usually show four stages of crystallization: (1) large phenocrysts of olivine and titaniferous augite; (2) smaller microphenocrysts of olivine, pyroxene, magnetite, and feldspar; (3) a fine groundmass of pyroxene, magnetite, and feldspar, but normally without much olivine; and (4) a residual mesostasis which may be wholly or partly vitreous but is more commonly composed of a mixture of plagioclase and subordinate orthoclase, nepheline, and analcime. Measurement reveals considerable differences in the proportions of phenocrysts and groundmass and it has been possible to distinguish a number of types.

(*a*) Olivine-poor; phenocrysts less than 15 per cent., pyroxene much in excess of olivine; e.g. [584], M. S. Antonio, 2½ km. east of Mindelo, S. Vicente.

(*b*) Olivine-poor with phenocrysts of feldspar.

(*c*) Phenocrysts about 30 per cent.; pyroxene equal to or slightly in excess of olivine; e.g. [768], Dike, S. Pedro lighthouse, S. Vicente, [Q.A27], Dike, Hayden's Retreat, Mindelo, S. Vicente.

(*d*) Phenocrysts 45 per cent. or over; pyroxene roughly twice as abundant as olivine; e.g. [767], Dike, S. Pedro lighthouse, S. Vicente.

In all these except (*b*) the microphenocrysts form a fairly consistent proportion at 5–8 per cent., plagioclase forming about half of this phase.

(*e*) Is characterized by a 'seriate' texture and 'clotting' of the pyroxene. Olivine amounts to about 15 per cent. These rocks seem to have certain affinities with the limburgitic basalts; e.g. [Q.A28] Hayden's Retreat, Mindelo, S. Vicente, [655] Quarry, south-west foot of M. Espia, Mindelo, S. Vicente.

(*f*) Mesostasis containing hornblende, biotite, and alkali feldspars recalling some of the lamprophyres of Rib. Areia Branca, east of Mindelo, described in the *Quest* Report; e.g. [623], Fort Hill, Mindelo, S. Vicente.

Minerals

Olivine. Phenocrysts up to 1 cm., but mostly usually 1–3 mm. euhedral or subhedral, colourless in thin section and mostly fairly fresh. Refractive indices indicate a magnesian-rich type with fairly small range in composition between 12 and 20 per cent. fayalite, mostly around 16 per cent. fayalite.[1] The value for [587], a dike from Rib. Areia Branca, is exceptionally high for these rocks.

Refractive indices of olivines in olivine-rich basalts from S. Vicente

No.	α	γ	Fa%
655 . . .	1·659	1·696	12
775 . . .	1·664	1·702	15
768 . . .	1·664	1·702	15
Q.A28 . .	1·666	1·705	16
767 . . .	1·667	1·705	16
726 . . .	1·670	1·708	18
Q.A27 . .	1·672	1·710	19
587 . . .	1·680	1·717	23

[1] L. R. Wager and A. W. Deer, *Amer. Min.* 1939, **24**: 21.

The usual alteration is to a pale green or yellowish serpentine having negative elongation and β 1·53–1·54 [768]. In some rocks the mineral is altered to an orange-coloured iddingsite [767].

Pyroxene. In almost all the rocks this is a violet-brown titanaugite, frequently quite strongly coloured, as in the specimens from east and north-east of Mindelo [587]. The outer zones are of deeper colour than the cores and a similarly deep-tinted variety forms the microlites of the groundmass. Pleochroism is moderate X violet-brown $>$ Y violet $>$ Z yellowish-brown. Dispersion is strong $\rho > v$ giving extinctions 2–3° higher for blue light than for red. Extinction $Z \wedge c$ is rather variable. Using sodium light the usual values lie between 43° and 48° in the cores and between 52° and 54° in the outer zones, 2V is 57–56° (core) and 53–52° (margin) positive. Refractive index values suggest that two main varieties occur, but at present there is no obvious connexion between the type of pyroxene and either the locality or any mineralogical or textural characters of the rocks.

	a [768]		*b* [Q.A28]	
	α	γ	α	γ
Core . .	1·697	1·722	1·710	1·725
Margin . .	1·700	1·725	1·715	1·730–1·737

In the mesostasis of some examples [623] the pyroxene tends to a greenish sodic variety (aegirine-augite) with higher extinction, $Z \wedge c$ around 60°.

Feldspar. The usual feldspar is labradorite, but in most of the sections examined there is strong zoning in both the microphenocrysts and the microlites of the groundmass. The most basic variety noted in the cores is An_{73} with a common value about An_{65-60}. Passing outwards from the core the value usually falls gradually to An_{30-25} with a rapid drop in the marginal zone to a variety with small or straight extinction and refractive index lower than Canada balsam. Where this is definitely plagioclase the composition is about An_{10-5}, but in most cases this feldspar is almost certainly a potash-bearing kind and in [623] is certainly orthoclase. Potash-feldspar occurs along with minor amounts of feldspathoid in the mesostasis of this and other specimens.

Nepheline. Occurs in minor amount in the mesostasis of certain specimens together with analcime, which latter also is found as a late-stage filling in vesicles and as an alteration product.

Magnetite. The usual form is as small octahedra 0·2–0·5 mm. in the microphenocrysts and in smaller crystals and grains in the groundmass. Only exceptionally present in larger grains of phenocrysts size 0·5–1·0 mm. [768]. This is consistent with the views expressed by Wager and Deer (1939) that this mineral does not separate below a certain concentration, not normally reached until sufficient magnesia has been removed from the liquid by early crystallization of magnesian olivine.

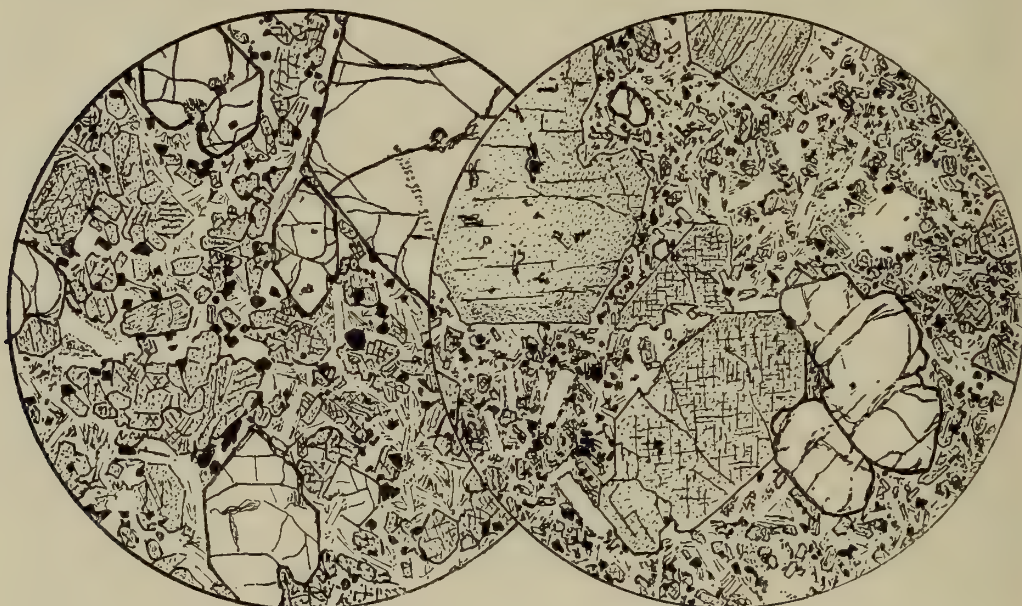
In those rocks having a vitreous (or originally vitreous) mesostasis magnetite occurs in it in rod-like skeletal forms. In view of the high titania-content of most of these rocks the mineral is in all probability a titaniferous variety or an intergrowth of magnetite and ilmenite.

Apatite. Universally present in all sections in the usual small needles in both groundmass and mesostasis.

Hornblende and biotite. In certain specimens minute brown flakes occur in the base. In most cases their straight extinction and cleavage indicate biotite, but more rarely the mineral is a brown sodic hornblende of low extinction [655] or a greenish variety with $Z \wedge c$ up to 23° [587]. The mesostasis of [623] contains both hornblende and biotite in narrow elongated microlites, the first having pleochroism X straw-yellow $<$ Y brown $<$ Z chestnut-brown, and $Z \wedge c$ 5–7°.

Description of some examples of the types of basalts (a, c–f)

Type a. [584]. Dike, foot of M. S. Antonio, $2\frac{1}{2}$ km. east of Mindelo, S. Vicente. Texturally similar to [768] (type *c*, below) from which it differs in relative poorness in



a *b*

FIG. 14. Olivine-basalts. (*a*) M. Espia, S. Vicente [655]. (*b*) S. Pedro lighthouse, S. Vicente [768]

olivine (4 per cent.) and pyroxenes (11 per cent.) phenocrysts. The pyroxene has $Z \wedge c$ 52–53° in the phenocrysts with 54° in the groundmass. Some microphenocrysts of plagioclase are zoned, An_{71-12}, with an outer skin of potash-feldspar, which also forms a considerable part of the feldspathic mesostasis.

Type c. [768], cliff path near lighthouse, S. Pedro, S. Vicente (Fig. 14*b*; analysis Table IV, column 1). Olivine-basalt dike in 'Main basalt' Series.

Phenocrysts 32%. 2–5 mm.	Titanaugite 16%, olivine 15%, magnetite 1% (in rounded or irregular grains up to 1 mm.).
Microphenocrysts 7%.	Plagioclase 4%, titanaugite 1%, olivine 1%, magnetite 1%. (All approximately 0·5 mm.)

Groundmass of euhedral titanaugite (0·1 mm.), plagioclase (0·1 mm.), and magnetite (0·03 mm.). There is very little mesostasis, partly of pale yellow glass, partly feldspathic. This feldspar is a potash-soda variety with low refractive index and extinction. Nepheline and analcime are insignificant in amount. Accessories are apatite and occasional small flakes of biotite.

Olivine and augite give the following figures for refractive indices, extinction angle, and 2 V:

	α	γ	$Z \wedge c$	2V
Olivine ($Fa_{15}Fo_{85}$)	1·664	1·702	—	(−) 89°
Titanaugite (core)	1·697	1·722	43°	(+) 57°
,, (margin)	1·700	1·725	47°	(+) 53°
,, (groundmass) . .	1·700	1·727	50°	—

The pyroxene phenocrysts show rather patchy zoning, giving a mottled appearance under crossed nicols, and in the microlites of the groundmass 'hour-glass' structure is common.

The feldspar occurs both in hypidiomorphic prisms and interstitial plates. It is mainly of An_{70-65}, falling to An_{23} in the outer zones, but in most crystals the margin is almost certainly rich in potash.

The chemical analysis compares well with that of a glassy olivine-basalt dike cutting lavas on Quail Island, an islet in the bay of Porto Praia, S. Tiago. It was collected by Charles Darwin and has been described by A. Harker (1907: 102). This rock ([C. 4713 = CD. 146]; analysis Table IV, column 2) belongs to a group of olivine-basalts related to limburgites. Its position in the volcanic sequence is not known, but limburgites are associated with the Miocene (Stage III) phonolites in the area, and also occur among the later Recent and Pleistocene (Stage IV) lavas. The rock [C. 4713] is a fine-grained type rich in euhedral titanaugite and olivine (2·0–0·25 mm.), the latter partly replaced by green serpentine. The base is a coffee-brown glass containing the usual microlites of augite and magnetite with the addition of plagioclase laths (0·05 mm.) of composition An_{50-45}.[1]

Type d. [767], S. Pedro lighthouse, S. Vicente, same locality as [768]. Olivine-basalt dike in 'Main basalt' Series.

Phenocrysts 44%.	Olivine (0·5–2·0 mm.) 14%
	Titanaugite (0·5–2·0 mm.) 29%
	Magnetite (0·2–0·5 mm.) 1%
Microphenocrysts 6%.	Olivine 1%
	Titanaugite 3%
	Magnetite 2%
	(All approximately 0·1–0·2 mm.)

The fine groundmass is composed of more or less idiomorphic pyroxene, plagioclase, magnetite, and olivine, all about 0·01 mm. in size, with a mesostasis of colourless glass containing a few patches of nepheline or potash-feldspar, but the total amount of

[1] A thin section shows some carbonate along cracks and margins of olivine phenocrysts. This may account for the 1·6 per cent. CO_2 in the analysis. W. C. S.

these latter is small.[1] Olivine (α 1·667, γ 1·705) is slightly more ferriferous (Fa_{16}) than in the previous example. Its mode of alteration takes the form of an orange or reddish iddingsite, starting as a thin marginal skin and thence spreading inwards in fibrous lamellae usually || to (001). The olivine grains of the groundmass are entirely replaced by this iddingsite, suggesting some enrichment in iron in this stage of crystallization.

Titanaugite has:

	α	γ	$Z \wedge c$
Core	1·713	1·725	47°
Margin and microlites . .	1·715	1·737	54°

Plagioclase is labradorite An_{70-65}, without, in this instance, notable zoning.

TABLE IV

ANALYSES

	1	*2*
SiO_2 . .	42·89	43·12
Al_2O_3 . .	11·58	12·94
Fe_2O_3 . .	2·13	1·98
FeO . .	12·78	9·52
MnO . .	0·19	0·26
MgO . .	10·01	8·09
CaO . .	11·22	12·62
Na_2O . .	1·92	2·65
K_2O . .	1·11	1·42
TiO_2 . .	4·52	3·45
P_2O_5 . .	0·26	0·44
CO_2 . .	0·20	1·60
H_2O+ . .	0·82	1·36
H_2O- . .	0·58	0·32
Totals .	100·21	99·77

NORMS

	1	*2*
or . .	6·1	8·34
ab . .	11·5	13·10
an . .	19·7	18·90
ne . .	2·6	5·11
di . .	26·5	25·00
ol . .	19·6	13·51
mt . .	3·0	3·02
il . .	8·5	6·54
ap . .	0·7	1·01
cc . .	—	3·60

1. Olivine-basalt, III'5'.(4)3.4. Near lighthouse, S. Pedro, S. Vicente. [B.M. 1915, 130, 768.]
2. Olivine-basalt, III.5(6).3.4. Quail I., entrance to Porto Praia, S. Tiago. [C. 4713 = CD. 146]. Part (G.M.). *Geol. Mag.*, 1947, **84:** 160.

Analyses by W. H. Herdsman.

Type e. [655], a 12-ft. dike running NE.–SW. in basalts, Quarry, south-west foot of M. Espia, 2½ km. east of Mindelo, S. Vicente. (Fig. 14*a*.)

Olivine 17 per cent., titanaugite 45 per cent., plagioclase 10 per cent., magnetite 7 per cent., mesostasis, chiefly feldspathic, 21 per cent.

The texture of this rock is unusual; most of the olivine occurs in euhedral phenocrysts (1–3 mm.) with a few smaller crystals grading down to 0·25 mm. It is fresh with only slight marginal alteration to a pale serpentine and is the least ferriferous variety encountered, having R.I. α 1·695, γ 1·696 (Fa_{12}).

[1] Q.A29 from Hayden's Retreat, described and figured in the *Quest* Report (1930: 124, fig. 22A and fig. 13A), is very similar. Interstitial nepheline is recorded in this specimen and was confirmed by a microchemical test.

The seriate texture is particularly noticeable in the pyroxene owing to the tendency for this mineral to 'clot' in patches composed of crystals of all sizes from 2·0 to 0·05 mm. with interstitial patches of feldspar and mesostasis between the clots. The pyroxene is generally euhedral, though the larger crystals tend to be spongy and filled with zones of irregular glass inclusions, but without marked differences in composition. It has R.I. α 1·714, γ 1·733–1·737, $Z \wedge c$ 50°.

Magnetite forms numerous little octahedra (0·1–0·25 mm.) in the groundmass where it is mainly concentrated round the edges of the pyroxenes.

Feldspar and mesostasis may be considered together. Part of this latter is a colourless glass and contains minor patches of nepheline and analcime, but most of the crystalline portion is plagioclase in small laths. The larger crystals of plagioclase range up to 0·3 mm. in size and An_{65-15} in composition. The rest have small or straight extinction and are probably of a potassic variety.

[Q.A28], a dike in the basalts at Hayden's Retreat, Mindelo, is very similar in its 'clotted' texture but is coarser in grain and has a mesostasis of brown glass. Its olivine is more ferriferous (Fa_{17}). (*Quest* Report, 1930: 124.)

Type f. [623], dike in lavas, Fort Hill, Mindelo, S. Vicente. This is one of the very few specimens in the collections in which olivine (18 per cent.) is in excess of pyroxene (16 per cent.) in the phenocrysts. These range up to 5 mm. and over in size. Olivine shows some incipient alteration to pale serpentine. It is mostly euhedral and also occurs (3 per cent.) with titanaugite (3 per cent.), plagioclase (1 per cent.), and magnetite (1 per cent.) in smaller microphenocrysts of 0·5–0·25 mm. size.

The groundmass is formed of a fine plexus of plagioclase laths, idiomorphic titanaugite, grains of olivine, and magnetite amounting to some 40 per cent. of the rock; the remaining 26 per cent. is an irregular, patchy mesostasis composed essentially of alkali-feldspar, mainly a soda-orthoclase, biotite, and brown alkali-hornblende with a small amount of slightly greenish alkali-pyroxene. All components tend to occur in elongated crystals up to 0·5 mm. in length. In the finer-grained and partly vitreous patches skeletal magnetite, plumose feldspar, and forked skeletal augites and hornblendes are common. The hornblende has the usual pale straw-yellow to chestnut-brown pleochroism with small extinction $Z \wedge c$ 5–7°. Apatite is abundant and there is a very little nepheline and analcime.

In the main portion of this rock olivine has R.I. α 1·668, γ 1·707 (Fa_{17}). Pyroxene is a violet-brown titanaugite with darker marginal zones and moderate pleochroism. R.I. and extinction angles are:

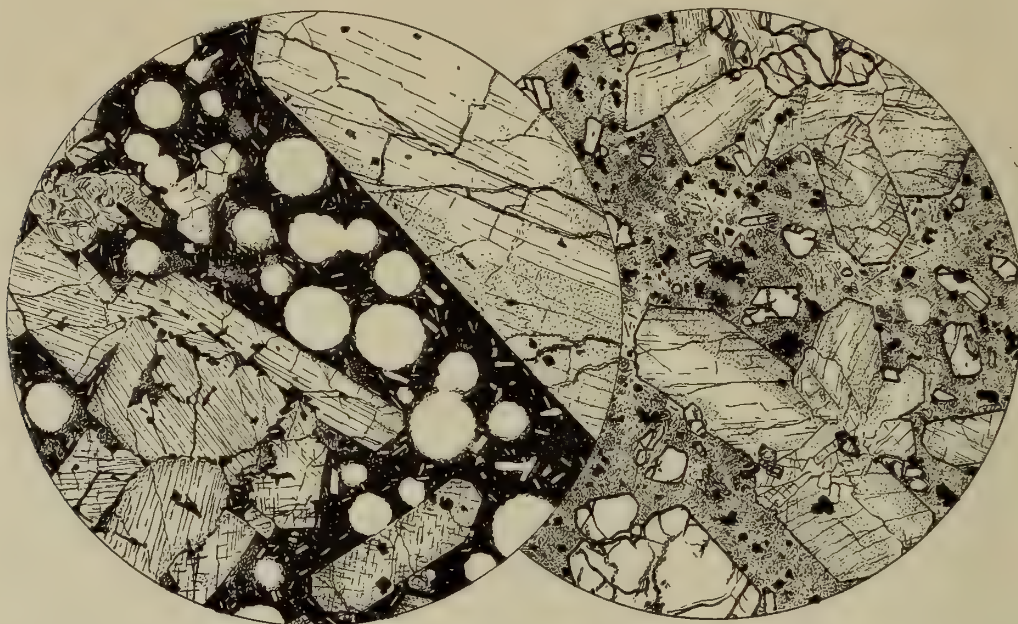
	α	γ	$Z \wedge c$
Core . . .	1·700	1·722	48°
Margin . . .	1·701	1·725	53°
Groundmass . .	1·701	1·725	53°

Plagioclase is zoned from An_{62} in the cores to, in some cases, as low as An_{10} in its outer zones with a final shell of potash feldspar.

[587], from R. Areia Branca, is noticeable for the tendency to form radial glomeroporphyritic aggregates exhibited by its pyroxene (Fig. 15*b*). Both pleochroism and

R.I. are slightly higher than in other specimens and the olivine has the highest Fa value observed in the present series of observations (p. 58).

[562] is a Stage III basalt from the east cliff at Tarrafal, S. Antão. Numerous large pyroxenes and partly serpentinized olivine lie in an almost opaque glassy base containing microlites of labradorite and pyroxene.



a *b*

Fig. 15. Olivine-basalts. (*a*) E. cliff, Tarrafal, S. Antão [562]. (*b*) R. Areia Branca, S. Vicente [587]

The last of these dikes which will be mentioned is [775], from the same locality as [767, 768]. It is coarsely porphyritic and amygdaloidal and to the naked eye apparently rich in olivine, but this appearance is deceptive, as measurement shows that of 58 per cent. phenocrysts only 20 per cent. are of olivine and the rest are of a pale greenish augite. The olivine (Fa_{15}) is much altered along cracks to greenish-yellow serpentine of mean R.I. 1535. The augite has α 1·685, γ 1·708 (core)–1·715 (margin). The groundmass is composed of a greenish-yellow glass crowded with euhedral augites, magnetite, and small poecilitic plates of plagioclase An_{60-58}. No potash feldspar or feldspathoid has been observed. The irregular amygdales often several millimetres across are filled with calcite and zeolites.

(*h*) *Limburgites and Augitites*

These two feldspar-free types, characterized by phenocrysts of augite and of augite and olivine respectively, set in both cases in a vitreous base containing microlites of augite and magnetite, are widely distributed in most of the islands as dikes and flows amongst the lavas of all stages of activity, and Bebiano (1932: 175 & 180) mentions that much of the area marked as 'basalt' on his map of S. Tiago consists of Recent

flows of this character. By reason of their simple mineralogical composition they tend to vary only in details.

A common type is represented by a Stage IV (Recent) rock from Morro de Salamanza, S. Vicente [729]. This is black, finely vesicular, and contains numerous euhedral olivines (1 mm.) in a base of coffee-brown glass charged with microlites of brown titanaugite and octahedra of magnetite. The vesicles about 1 mm. across are filled with calcite and analcime. [420], 1 km. south-west of Carvoeiros, S. Antão, another Recent flow, is similar to the last with olivines about 0·5 mm. and augite microlites (in the base) 0·01–0·05 mm.

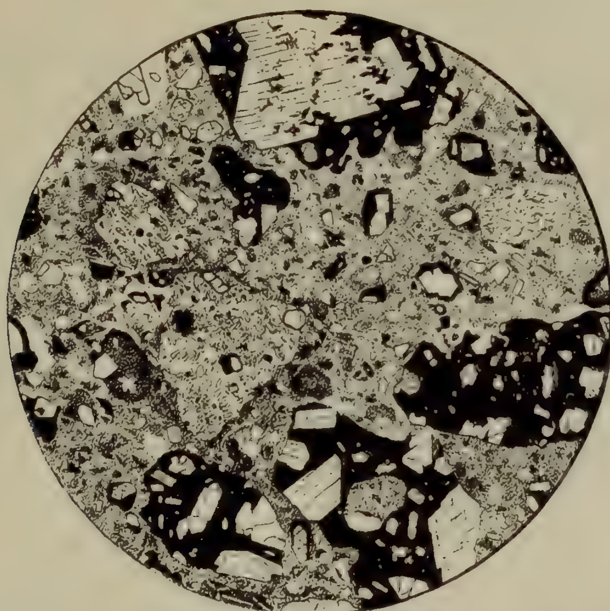


FIG. 16. Limburgite tuff, Campo Preguiça, S. Nicolao [355]

[26], north slope above Fonte Vinagre[1] and [86] agglomerates, mouth of R. 'Lacacan', Brava, both associated with phonolites, are black, scoriaceous rocks containing many phenocrysts of olivine and augite (0·25–1·25 mm.) in a fine vesicular base of pale colourless glass containing augite microlites and minute octahedra of magnetite. The augite is pale brown ($Z \wedge c$ 48°), but many of the phenocrysts have cores of greenish aegirine-augite, possibly xenocrystal in origin with $Z \wedge c$ up to 63°.

Two tuffs, [99], 'Minhoto', Brava, and [355], Campo Preguiça, S. Nicolao, contain numerous fragments of limburgite. The first of these is mainly a phonolite-tuff, but the limburgite fragments contain particularly well-crystallized augites up to 2·5 mm. The similar-sized olivines have been completely replaced by ferruginous calcite which also fills numerous circular vesicles up to 1 mm. across. The S. Nicolao rock is basaltic in character. The limburgite fragments show abundant well-crystallized augite and olivine in the usual dark-brown glassy base (Fig. 16).

[1] [26], about half-way between Ribeira do Vinagre and Furna. W. C. S.

Harker (1907: 102) has described the *Beagle* specimens from S. Tiago and little need be added to his account except that in [CD. 4706] from Quail I., Praia, described by him as a fourchite (p. 103), the base is a glass, and analcime is confined to the vesicles. A common type amongst these S. Tiago limburgites is characterized by the 'clotting' of the little augites of the base into stellate groups and by the skeletal 'fir-tree' growths of the magnetite belonging to this phase of crystallization (Fig. 12*b*). Others show the incoming of feldspar in the base passing into the limburgite-basalts [C. 4713] already described (p. 61).

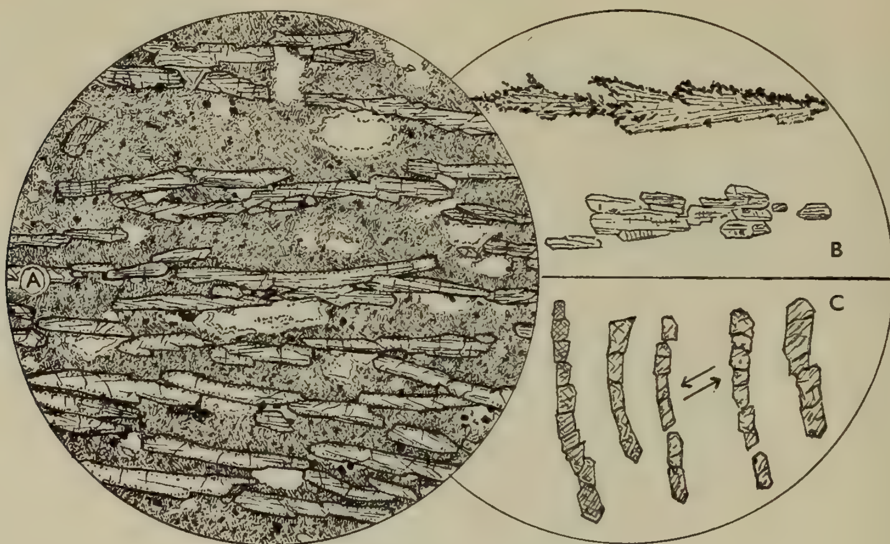


FIG. 17. Augitite, Bird I., S. Vicente [B.M. 64614]

Limburgites also occur among the newer lavas of Fogo, and consist of the usual brown, glassy base crowded with microlites of titanaugite and magnetite and are rich in phenocrysts of titanaugite and olivine up to 1 mm. in size ([820], R. João Pinto, and [836], shore, 1·5 km. south of S. Filipe).

An augitite, [B.M. 64614], from the Challenger Collection, labelled 'dyke, Bird I. near St. Vincent, C. Verde Is.', has been recently described by the present author (1946: 241).[1] Of quite simple mineralogical composition, phenocrysts of brown titanaugite set in a base of pale glass with microlites of similar augite and magnetite grains it is chiefly noteworthy for its unusual texture (Fig. 17*a*). The specimen has a 'worm-eaten wood' appearance owing to the numerous very long and narrow parallel vesicles. The black titanaugite phenocrysts are long and narrow and both these features die out towards one end of the specimen suggesting that this is the chilled margin of the dike. The pyroxenes range up to 5 mm. or more in length elongated in

[1] This specimen was described by A. F. Renard (1889: 17) as 'a somewhat fibrous lava, which may be classed with the Pyroxenites . . .' using this name in the sense used by Doelter (1882: 137). Renard commented on the unusual length of the slender augite crystals recording lengths of 7 to 8 mm. and a breadth of 0·1 mm. W. C. S.

their *c*-direction, flattened || (100). Towards the marginal part of the specimen these become ragged and plumose in character with magnetite granules entangled in the outer layers (Fig. 17*b*). Crystallization started at the chilled margin; next the pyroxene phenocrysts began forming in the interior growing rapidly outwards towards the margin normal to the cooling surface; flow continued during consolidation of the groundmass, as is shown by the orientation of the pyroxene microlites parallel to the cooling surface and mainly across the line of elongation of the phenocrysts. This continued movement has imposed a shearing stress upon these latter, relieved by fracture along one of the prismatic cleavages (Fig. 17*c*).

Extinction angles of the pyroxenes indicate a progressive change in its composition during the course of crystallization.

$Z \wedge c$ microlites of fine margin	54–56°
phenocrysts core	56–59°
,, skin	up to 63°
microlites of vesicular groundmass	up to 63°
pyroxene of later vesicular infilling	65°

Most of the vesicles are empty apart from a thin lining of pale glass, but in some there is a late infilling of feldspar either oligoclase (Ab_{75}) or a potash-bearing variety and there are other patches filled with glass, titanaugite, and elongated flakes of biotite coarser in texture than the general body of the groundmass.

Lastly may be mentioned a leucite-bearing augitite [196] underlying the Recent raised beach at Praia, S. Tiago. This is rich in titanaugite crystals, 0·1–0·75 mm. in length, with $Z \wedge c = 54°$. Magnetite (up to 0·25 mm.) is abundant. The base is a coffee-brown glass crowded with small augites and magnetites and it contains numerous little leucites up to 0·1 mm. in diameter.[1]

IV. Chemistry and Petrogenesis

In Tables V and VI have been assembled 49 analyses, 31 published by Bebiano, Ermert, and Lacroix and including 18 made for the present author from specimens in the Child and Darwin collections. It has not seemed necessary to quote again the figures published by Doelter. After upwards of sixty years' service these may be allowed to pass into honourable retirement.

In one respect the new figures are unsatisfactory—in that they are spaced, and unevenly, over too wide a field—and it is clear that we need more detailed information about each individual island centre. It is to be hoped that future workers in this field will concentrate on one island at a time, map it in detail, and work out the chemical and petrological changes right through its volcanic succession. At this juncture it does not seem very profitable to indulge in speculation about the origin and petrogenesis of these rocks, but there are, nevertheless, a number of points about them to which attention may be usefully directed.

(*a*) *Absence of 'acid' types.* Up to date no rock containing visible quartz has been

[1] Lacroix identified as leucite similar 'cristaux globuleux . . ., à contours vagues, caractérisés par la disposition zonaire de leurs inclusions d'augites' (*Bull. Soc. Géol. Fr.* 1910, ser. 4, **10:** 114). Later, however, in view of the chemical composition of the rock, he referred them to primary analcime (*Mém. Acad. Sci. Fr.* 1928, ser. 2, **59:** 17). W. C. S.

reported from any of the islands and there appears to be a complete absence of the alkaline rhyolites and trachytes found in comparable suites in other Atlantic islands and in Africa. The nearest approach to acid types are certain trachytes from S. Antão [520] and S. Nicolao [324] in which quartz appears in the norm, though too much significance need not be attached to this (see Table I, columns 5 and 6).

(*b*) *Comparative scarcity of 'intermediate' types.* It is possible that more intensive collecting would fill the gaps, but one of the more striking features of this suite, as represented in these collections, is the division into phonolites (and their intrusive equivalents) on the one hand and basic alkaline 'basalts' on the other. Bebiano mentions certain rocks (mainly from S. Antão) which appear to be trachy-andesites or trachy-basalts and others which are obviously 'basic' derivatives of the phonolites, but such appear to play a very subordinate part in the suite as a whole. In spite of its unpopularity amongst present-day petrologists it seems difficult to rule out the possibility of a measure of immiscibility between the two main groups. C. N. Fenner[1] has recently drawn attention to the possible importance of this principle and to the inability of the standard conception of crystal differentiation to explain many of the observed facts of rock formation. In particular he has stressed that the normal progress of crystallization in 'basaltic' magmas leads to the maintenance of a more or less constant value for silica with reduction in lime and magnesia and enrichment in ferrous iron. In the ordinary way such a magma cannot produce (except in the final stages and under the influence of volatiles) any appreciable quantity of acid component. It is clear that these alkaline basalts do not normally give rise to 'phonolite' as a product of their own crystallization. What they do produce is a rock low in silica, minus most of the olivine and much of the magnesian pyroxene, comparatively rich in alkalies and in ferrous iron and the effects of volatiles. Expressed in mineralogical terms, we should expect to find alkali-feldspars in some predominance with such iron-bearing minerals as alkali-amphiboles and much titanium-rich ores with analcime and zeolitic alteration, in other words, lamprophyres. Far from being the aberrant curiosities which they are commonly considered, the 'camptonitic' lamprophyres found among the basalt series in these islands fall into their right place as the normal end-product to be expected from basic rocks of the type under discussion.[2]

(*c*) Chemically these basalts are characterized by generally low figures for silica (39–43 per cent.) together with high values for iron and titanium. What would appear to be of much greater importance than the presence or absence of certain feldspars and feldspathoids is that the principal minerals—anorthite, nepheline, magnesian olivine, and pyroxene—*all have a silica percentage of 43–45, i.e. approxi-*

[1] Clarence N. Fenner, *Journ. Geol.*, 1937, **45:** 158–168.

[2] Rocks belonging to this group (lamprophyres) occur all through the early and middle parts of the volcanic sequence, beginning in the Eocene intrusions in the Neocomian of Maio (Stage I). Camptonites and allied lamprophyres cut the 'Main basalt' series of S. Vicente and grains of similar rocks are found in the Miocene limestones of S. Tiago. A camptonite dike from the same neighbourhood (Praia) is included in the Darwin Collection [CD. 105] and a number of very decomposed hornblende-lamprophyres come from dikes veining the metamorphosed limestones of Fogo in both R. Trinadade and R. 'Montindor'.

The hornblende-augite lamprophyres, allied to camptonite, of the R. Areia Branca area, north-east of Mindelo [Q.A4], have been described by the present author in the *Quest* Report (1930: 120). There are some examples of these in the Child Collection, but they differ in no way from those previously described. G. M. P.

mately the same or slightly higher than that of the rocks which contain them. It is easy to see that very slight differences in composition or in the equilibrium factors upon which mineral formation depend may result in comparatively large differences in the proportions of the main minerals present and so give rise to the multiplicity of basic alkaline rock-types actually found in the area.

It must further be remembered that the pyroxenes and amphiboles are, in Fenner's phrase, a 'catch-all' for otherwise inconvenient constituents, particularly silica and ferric iron. Average values for the pyroxenes found in these classes of rock show silica percentages ranging from 45–47 per cent. (titanaugite) to 50 per cent. (aegirine-augite), rising to 52 per cent. in the aegirine of the phonolites illustrating the 'buffer' function of the pyroxenes in these rocks. Progressive enrichment in ferrous iron and titanium as crystallization proceeds means that much of the ore-mineral present is of late formation, and since only a portion of the total titanium present can be accommodated in the pyroxene, it is likely that much of it is present either in the magnetite itself or as an intergrowth of titaniferous magnetite and ilmenite. In the phonolites 'excess' titanium appears in sphene, universally present often in considerable quantity.

(*d*) *Richness in lime.* Among the basic lavas this component enters very largely into the abundant pyroxene—a further example of the buffer function of these minerals—and into early-formed calcic feldspar when present, but many of the phonolites (and their intrusive equivalents) must be classed with the nepheline-monzonite family rather than with the nepheline-syenites. This lime-rich character of the suite as a whole appears to be a primitive feature and prompts the suggestion that some contamination from the Mesozoic sediments which form the underlying foundation of the archipelago may have played a part in the petrogenesis of these lavas.

(*e*) So far as can be inferred from the specimens and other evidence obtainable, the Stage II 'Main basalts' are both widespread and fairly uniform in character, but subsequent phases are extremely local in type, particularly among the phonolites, which vary characteristically from one island to another, suggesting that the reservoirs from which they are drawn are of no great size. Phonolites, moreover, are very restricted in time, being confined to the Miocene (Stage III) phase of the sequence, a state of affairs comparable to that found in East and Equatorial Africa with the rocks of which this suite has obviously much in common. The Recent (Stage IV) lavas are again of widespread and fairly uniform type, suggesting that the new cycle of activity has not yet proceeded sufficiently long to effect any appreciable differentiation in its products.

TABLE V

Analyses of Rocks from S. Antão, S. Vicente, S. Nicolao, S. Tiago, Fogo, and Brava

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
SiO_2	56·22	47·63	37·38	43·67	54·18	46·95	51·16	38·94	53·65	53·76
Al_2O_3	22·74	18·94	18·03	17·58	21·52	18·98	21·53	13·64	20·56	22·18
Fe_2O_3	0·84	1·47	8·61	4·91	1·93	3·64	2·64	6·44	1·00	1·33
FeO	2·71	8·12	3·22	7·08	1·74	1·47	1·86	4·81	1·36	2·53
MnO	0·26	0·28	0·26	0·27	0·08	0·15	0·07	0·34	0·08	0·09
MgO	0·76	3·52	8·04	5·77	0·76	0·79	0·68	3·88	1·28	0·15
CaO	1·94	6·94	12·42	10·58	2·61	5·34	1·92	15·79	4·50	2·10
Na_2O	6·07	5·85	3·68	4·62	4·14	9·39	10·53	1·98	6·34	8·74
K_2O	3·13	3·71	1·51	1·14	4·27	5·93	5·69	1·69	5·08	5·96
TiO_2	0·56	2·56	2·57	2·56	0·68	0·63	0·49	3·95	1·30	0·39
P_2O_5	0·04	0·64	1·49	0·69	0·08	0·14	0·05	1·23	0·30	tr.
CO_2	tr.	0·15	tr.	tr.	—	1·66	tr.	tr.	0·24	tr.
Cl	0·09	0·18	n.d.	—	0·15	0·31	0·34	0·07	—	0·37
SO_3	0·26	0·27	n.d.	—	0·06	0·19	1·14	0·24	—	0·18
H_2O+	3·34	0·03	1·34	0·84	4·36	2·89	1·72	4·51	3·30	2·01
H_2O-	1·16	0·04	1·19	0·16	3·30	1·69	0·45	3·00	0·27	0·24
Totals	100·12	100·33	99·74	99·87	99·86	100·15	100·27	100·51	99·26	100·03
Less O for Cl.	0·02	0·04	—	—	0·03	0·07	0·08	0·02	—	0·08
Net Totals	100·10	100·29	99·74	99·87	99·83	100·08	100·19	100·49	99·26	99·95

	11	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*
SiO_2	44·55	40·16	43·12	56·26	54·97	54·53	52·18	55·11	51·59	48·71
Al_2O_3	11·62	10·34	12·94	18·68	20·06	18·90	19·07	19·27	18·90	19·62
Fe_2O_3	5·53	5·18	1·98	3·61	3·43	5·01	3·36	2·67	4·61	4·18
FeO	5·20	8·44	9·52	1·87	1·25	1·74	1·30	1·41	6·10	7·37
MnO	0·18	0·15	0·26	0·81	0·21	0·18	0·07	0·08	—	—
MgO	9·40	11·58	8·09	0·22	0·43	3·57	1·58	0·05	3·20	4·71
CaO	13·16	13·20	12·62	2·36	2·60	3·43	4·56	1·33	7·23	8·36
Na_2O	2·19	2·37	2·65	7·19	8·27	5·29	4·06	9·11	3·81	3·07
K_2O	1·86	0·66	1·42	5·21	5·14	3·48	5·51	6·54	2·33	1·90
TiO_2	3·24	4·56	3·45	0·60	0·64	1·54	1·24	0·17	1·03	1·21
P_2O_5	0·48	0·38	0·44	0·31	0·20	0·24	0·38	0·08	0·36	0·42
CO_2	0·08	nil	1·60	1·49	0·99	—	—	2·10	—	—
Cl	n.d.	0·38	n.d.	0·11	—	—	0·06	0·46	—	—
SO_3	n.d.	nil	n.d.	—	—	—	—	—	—	—
H_2O+	1·31	2·12	1·36	0·99	2·17	2·66	5·30	1·59	1·36	1·12
H_2O-	0·15	0·32	0·32	0·31	—	0·85	1·92	0·29	—	—
Totals	98·95	99·84	99·77	100·02	100·36	101·42	100·59	100·26	100·52	100·67
Less O for Cl.	—	0·09	—	0·02	—	—	0·01	0·10	—	—
Net Totals	98·95	99·75	99·77	100·00	100·36	101·42	100·58	100·16	100·52	100·67

	21	*22*	*23*	*24*	*25*	*26*	*27*	*28*	*29*	*30*
SiO_2	42·89	43·58	36·77	38·60	39·13	49·81	42·18	42·53	42·08	41·52
Al_2O_3	11·58	9·99	9·80	11·64	10·20	20·76	14·01	9·48	15·03	15·24
Fe_2O_3	2·13	2·56	3·79	9·44	4·40	2·92	4·58	3·22	3·25	3·99
FeO	12·78	8·78	7·89	5·33	8·93	1·80	8·28	10·66	8·68	6·27
MnO	0·19	0·13	0·14	0·71	0·15	0·13	0·13	0·24	0·33	0·21
MgO	10·01	11·50	14·94	6·23	12·72	0·99	5·90	11·56	5·52	5·07
CaO	11·22	13·36	15·67	14·43	13·03	4·65	13·16	14·83	12·74	11·17
Na_2O	1·92	2·28	2·49	5·43	3·32	8·95	3·69	2·22	4·16	5·68
K_2O	1·11	1·71	0·97	2·49	0·61	6·19	2·26	1·02	2·84	3·73
TiO_2	4·52	3·97	4·07	4·23	4·98	1·10	5·06	4·02	4·24	3·89
P_2O_5	0·26	1·33	1·40	0·80	0·77	0·23	0·82	0·21	0·77	1·20
CO_2	0·20	—	—	—	0·52	0·21	—	0·15	nil	nil
Cl	n.d.	0·06	0·06	0·05	0·02	nil	—	n.d.	n.d.	n.d.
SO_3	n.d.	—	—	—	—	0·35	—	n.d.	n.d.	n.d.
H_2O+	0·82	1·14	1·87	0·40	1·10	0·76	0·21	tr.	0·08	0·56
H_2O-	0·58	0·34	0·39	0·78	0·26	0·23	0·10	0·13	0·16	0·26
Totals	100·21	100·73	100·25	100·56	100·14	99·08	100·38	100·27	99·88	98·79
Less O for Cl.	—	0·01	0·01	0·01	—	—	—	—	—	—
Net Totals	100·21	100·72	100·24	100·55	100·14	99·08	100.38	100.27	99·88	98·79

TABLE V (*continued*)

1. Hornblende-trachyte, R. da Tôrre, S. Antão. [520.] (Herdsman.)
2. Tahitite, E. cliff, Tarrafal, S. Antão. [542.] (Herdsman.)
3. Melilite-nephelinite, E. cliff, Tarrafal, S. Antão. [555.] (Herdsman.)
4. Hornblende-tephrite, E. cliff, Tarrafal, S. Antão. [563.] (Herdsman.)
5. Hornblende-trachyte, Rio Brava valley, Vila, S. Nicolao. [324.] (Herdsman.)
6. Leucite-phonolite, above Fonte Vinagre, Brava. [163.] (Herdsman.)
7. Haüyne-phonolite, 1½ km. S. of Furna, Brava. [27.] (Herdsman.)
8. Melanite-haüynite, mouth of R. 'Lacacan', Brava. [62.] (Herdsman.)
9. Monzonitic nepheline-syenite, R. S. Jorge, 5 km. N. of Praia, S. Tiago. [271.] (Herdsman.)
10. Hornblende-melanite-phonolite, M. S. Pedro, 5 km. N. of Praia, S. Tiago. [202*a*.] (Herdsman.)
11. Essexite, R. S. Jorge, 5 km. N. of Praia, S. Tiago. [273.] (Geochemical Laboratories.)
12. Olivine-nephelinite, M. S. Pedro, 5 km. N. of Praia, S. Tiago. [216.] (Herdsman.)
13. Olivine-basalt, W. side, Quail I., S. Tiago. [CD. 146 = C. 4713.] (Herdsman.)
14. Nepheline-syenite, Pedras Brancas, S. Vicente. (Mário de Jesus, p. 260.)
15. ,, ,, ,, ,, ,, (Schlunz, p. 158.)
16. Trachyandesite, between Pedras Brancas and Bahia de S. Pedro, S. Vicente. (Schlunz, p. 165.)
17. Trachyte, 1,300 m. N. 15° W. of M. Fateixa, S. Vicente. (Mário de Jesus, p. 262.)
18. Sodalite-phonolite, M. Cavalo, S. Vicente. (Mário de Jesus, p. 246.)
19. Trachydolerite, Salamanza, S. Vicente. (Reinisch, p. 655.)
20. ,, ,, N. of pier, Mindelo, S. Vicente. (Reinisch, p. 656.)
21. Olivine-basalt, cliff-path near lighthouse, S. Pedro, S. Vicente. [768.] (Herdsman.)
22. Basanite (Basanitoid), 8 km. from Mindelo, Mindelo–Viana road, S. Vicente. (Mário de Jesus, p. 255.)
23. Melilite-ankaratrite, 1 km. N. 15° W. from trigonometrical station, M. Verde, S. Vicente. (Mário de Jesus, p. 249).
24. Nepheline-ankaratrite, 200 m. N. of Casa de Nhá Cláudia, S. Vicente. (Mário de Jesus, p. 252.)
25. ,, ,, 1 km. S. 30° W. of M. Amargosa, S. Vicente. (Mário de Jesus, p. 254.)
26. Haüyne-phonolite, 5 km. up R. Trinadade, Fogo. [807.] (Geochemical Laboratories.)
27. Nepheline-basanite, Patim, Fogo. (Raoult, p. 199.)
28. ,, ,, R. João Pinto, Fogo. [812.] (Herdsman.)
29. Tephrite, R. Trinadade, Fogo. [779.] (Herdsman.)
30. Leucite-nephelinite, 3 km. up R. Trinadade, Fogo. [806.] (Geochemical Laboratories.)

Analysts' names are given in parentheses. The numbers in square brackets refer to the Child Collection [B.M. 1915, 130] excepting CD. 146 which is from the Beagle Collection. The analyses of these are new. The rest are quoted from the following publications:

A. Mário de Jesus, Anexo I to J. B. Bebiano, A geologia do Arquipélago de Cabo Verde. *Com. Serv. Geol. de Portugal*, **18** (1932).

(Raoult) in J. B. Bebiano (above).

(Schlunz) in H. Ermert, *Chemie der Erde*, **10**, pt. 2 (1936).

(Reinisch) in *Gesteine der Atlantischen Inseln, Deutsche Südpolar Expedition*, **2**, part 1 (Berlin. 1906).

TABLE VI

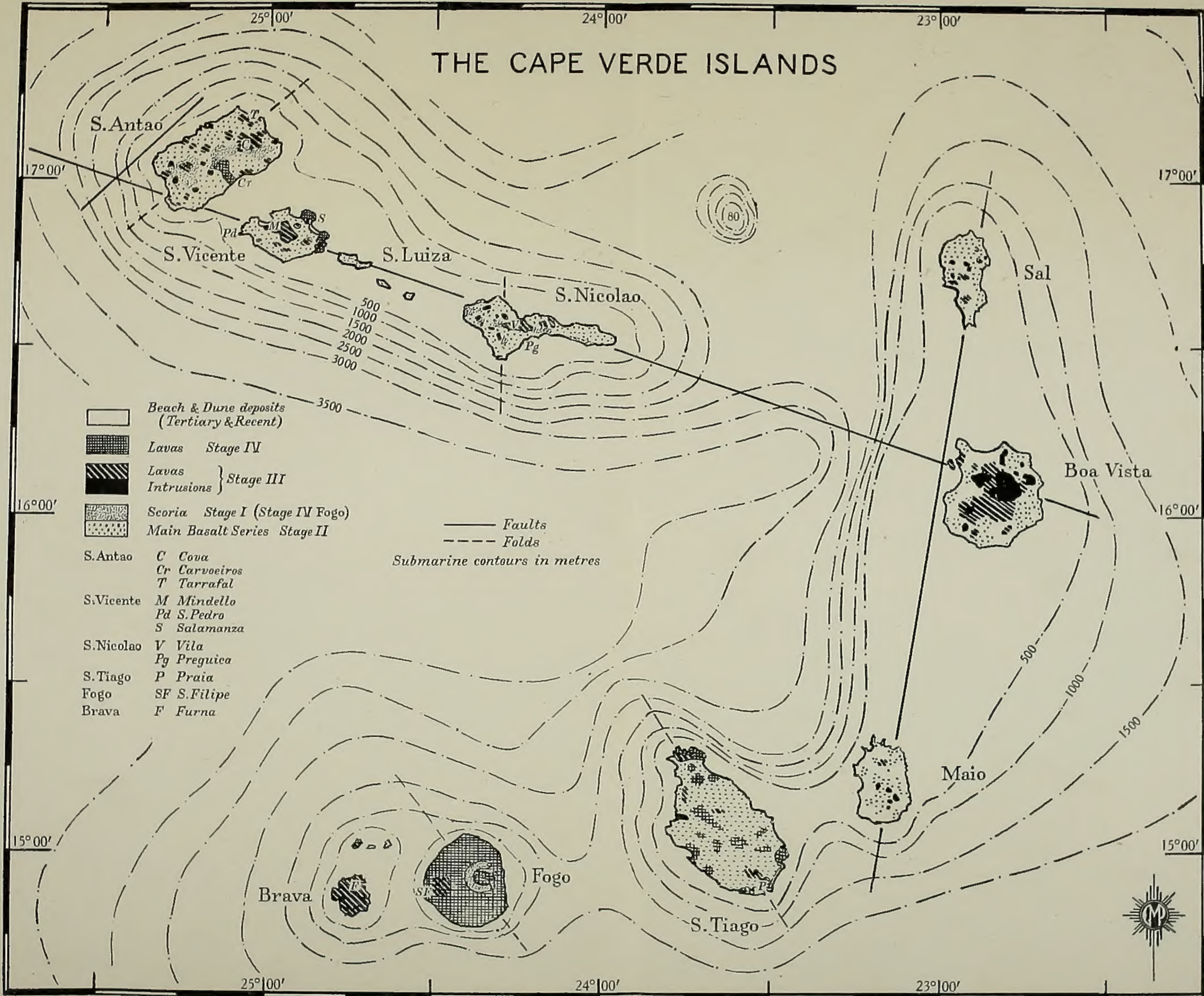
Analyses of Rocks from Sal, Maio, and Boa Vista, Cape Verde Is.

	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	*I*	*J*
SiO_2	55·50	48·96	53·18	54·66	49·27	43·56	38·03	37·18	37·86	43·46
Al_2O_3	20·52	18·24	19·62	21·96	22·69	16·17	13·63	10·37	4·37	14·13
Fe_2O_3	1·62	3·57	3·39	1·10	0·74	5·61	9·07	5·64	5·14	6·81
FeO	1·38	4·48	3·57	2·19	2·73	8·59	3·45	7·53	9·00	7·00
MnO	0·43	0·25	0·04	0·21	0·13	0·15	0·16	0·26	—	n.d.
MgO	0·18	1·49	1·40	0·35	3·12	6·09	8·55	12·52	22·78	5·18
CaO	0·92	6·12	4·84	3·02	5·99	8·22	15·42	15·08	13·62	12·56
Na_2O	10·37	6·48	7·45	8·91	5·97	4·47	1·88	2·87	1·53	2·96
K_2O	4·63	3·99	3·84	5·55	4·02	1·76	0·76	0·93	1·02	1·39
TiO_2	0·40	1·96	1·80	0·81	3·24	3·80	5·06	4·60	3·38	4·23
P_2O_5	tr.	0·42	0·42	0·18	0·33	0·55	0·89	0·82	0·29	0·59
CO_2	—	1·88	tr.	—	0·54	—	tr.	0·14	—	—
Cl	—	0·05	0·09	—	—	—	—	—	—	0·15
SO_3	—	tr.	tr.	—	—	—	—	—	—	—
H_2O+	3·89	2·17	0·67	0·74	1·68	0·94	3·22	1·58	1·19	1·81
H_2O-	0·44	0·30	0·20	0·28	—	—	—	0·89	—	0·13
Totals	100·28	100·36	100·51	99·96	100·45	99·91	100·12	100·41	100·18	100·40
Less O for Cl.	—	0·01	0·02	—	—	—	—	—	—	0·03
Net Totals	100·28	100·35	100·49	99·96	100·45	99·91	100·12	100·41	100·18	100·37

	K	*L*	*M*	*N*	*O*	*P*	*Q*	*R*	*S*
SiO_2	41·60	44·38	44·00	41·94	36·24	36·16	59·16	46·40	35·76
Al_2O_3	11·88	16·84	14·54	12·91	8·22	6·85	18·46	12·93	9·76
Fe_2O_3	5·07	3·34	6·51	4·24	5·45	6·27	2·04	5·69	4·70
FeO	7·24	5·00	4·29	8·28	6·32	6·94	1·99	6·18	6·48
MnO	0·12	0·17	0·13	0·08	0·13	—	0·34	0·11	0·21
MgO	7·12	2·70	3·85	8·15	16·66	13·88	0·74	7·50	16·97
CaO	13·42	9·12	11·22	12·78	17·18	18·88	1·38	12·02	15·28
Na_2O	3·39	7·17	4·79	2·64	2·67	2·65	7·50	2·67	3·46
K_2O	0·51	3·15	1·39	1·28	1·11	1·00	4·99	1·10	1·38
TiO_2	4·98	3·36	4·42	5·24	3·20	4·61	1·39	3·62	3·48
P_2O_5	0·71	0·77	1·11	0·65	1·14	0·79	0·06	0·60	1·37
CO_2	0·17	0·11	tr.	—	tr.	—	—	—	0·25
Cl	—	0·13	—	—	—	—	—	—	0·05
SO_3	—	0·12	—	—	—	—	—	—	tr.
H_2O+	3·44	3·34	2·87	1·74	1·61	2·07	1·76	0·84	0·76
H_2O-	0·46	0·63	0·98	0·33	0·32	0·36	0·49	0·69	0·13
Totals	100·11	100·33	100·10	100·26	100·25	100·46	100·30	100·35	100·04
Less O for Cl.	—	0·03	—	—	—	—	—	—	—
Net Totals	100·11	100·30	100·10	100·26	100·25	100·46	100·30	100·35	100·04

A. Nepheline-syenite (monzonitic), 1,200 m. N. 13° W. of Morro de Carvao, Sal. (Raoult, p. 124.)
B. Nepheline-monzonite, 1,500 m. N. of Casa de Soldado, Sal. (Raoult, p. 125.)
C. ,, ,, 2 km. S. 25° E. of Palmeira village, Sal. (Raoult, p. 125).
D. Nepheline-phonolite, 300 m. E. of Curralona, Sal. (Raoult, p. 127.)
E. Dioritic essexite, 500 m. NW. of Morro das Pedras, Sal. (Schlunz, p. 163.)
F. Essexite-gabbroid dolerite, between Morro das Pedras and Morro de Carvao, Sal. (Schlunz, p. 168.)
G. Augitite, Pedra Lume, Sal. (Schlunz, p. 173.)
H. Ankaratrite, Porto de Sta Maria, Sal. (Raoult, p. 128.)
I. ,, melilitic olivine-rich, Sal. (Raoult, *Min. de Mad.*, p. 65.)
J. Luscladite, Sal. (Raoult, *Miss. au Tibesti*, p. 264.)
K. Olivine-basalt (Ankaramite), 1 km. SE. of Morro, Maio. (Raoult, p. 159.)
L. Monchiquite, M. d'Água, Maio. (Raoult, p. 162.)
M. Nepheline-basanite, Ponta Pedrenau, Maio. (Raoult, p. 157.)
N. Ankaratrite, Ponta de Osso de Baleia, Maio. (Raoult, p. 158.)
O. ,, melilitic, M. Batalha, Maio. (Raoult, p. 160.)
P. ,, melilitic (olivine-rich), Maio. (Raoult, *Min. de Mad.*, p. 65.)
Q. Monzonite-syenite, Cabeço de Tarrafes, Boa Vista. (Raoult, p. 137.)
R. Dolerite, Morro Negro, Boa Vista. (Raoult, p. 138.)
S. Melilitic basalt (ankaratrite), M. Abrohal, Boa Vista. (Raoult, p. 142.)

Analysts' names are given in parentheses.
E, F, G are from H. Ermert, *Chemie der Erde*, **10** (1936).
I, P are from A. Lacroix, *Min. de Madagascar*, **3** (1923).
J is from A. Lacroix, 'Mission au Tibesti', *Mém. Acad. Sci. de l'Inst. de France*, **61** (1934).
The rest are from J. B. Bebiano, 'A geologia do Arquipélago dé Cabo Verde', *Com. Serv. Geol. Portugal*, **18** (1932).


THE CAPE VERDE ISLANDS
25° 00′
24° 00′
23° 00′
17° 00′
16° 00′
15° 00′
S. Antao
S. Vicente
S. Luiza
S. Nicolao
Sal
Boa Vista
Maio
S. Tiago
Fogo
Brava
T
C
Cr
Pd
M
S
V
Pg
P
SF
F
80
500
1000
1500
2000
2500
3000
3500
Beach & Dune deposits (Tertiary & Recent)
Lavas Stage IV
Lavas
Intrusions
Stage III
Scoria Stage I (Stage IV Fogo)
Main Basalt Series Stage II
Faults
Folds
Submarine contours in metres
S. Antao C Cova
Cr Carvoeiros
T Tarrafal
S. Vicente M Mindello
Pd S. Pedro
S Salamanza
S. Nicolao V Vila
Pg Preguica
S. Tiago P Praia
Fogo SF S. Filipe
Brava F Furna

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